# Overview of the Iowa Flood Center and the Projected Changes in Flooding across Iowa

Gabriele Villarini and Witold Krajewski

IOWA | College of Engineering

IIHR Hydroscience & Engineering

Iowa Flood Center

## DIVISION VI

### Sec. 15. NEW SECTION. 466C.1 IOWA FLOOD CENTER

1. The state board of regents shall establish and maintain in Iowa City as a part of the state university of Iowa an Iowa Flood Center. In conducting the activities of this chapter, the center shall work cooperatively with the department of natural resources, the department of agriculture and land stewardship, the water resources coordinating council, and other state and federal agencies.
2. The Iowa flood center shall have all of the following purposes:
   a. To develop hydrologic models for physically based flood frequency estimation and real-time forecasting of floods, including hydraulic models of flood plain inundation mapping.
   b. To establish community-based programs to improve flood monitoring and prediction along Iowa's major waterways and to support ongoing flood research.
   c. To share resources and expertise of the Iowa flood center.
   d. To assist in the development of a workforce in the state, knowledgeable regarding flood research, prediction, and mitigation strategies.

# IOWA HOUSE FILE 822

Spring 2009

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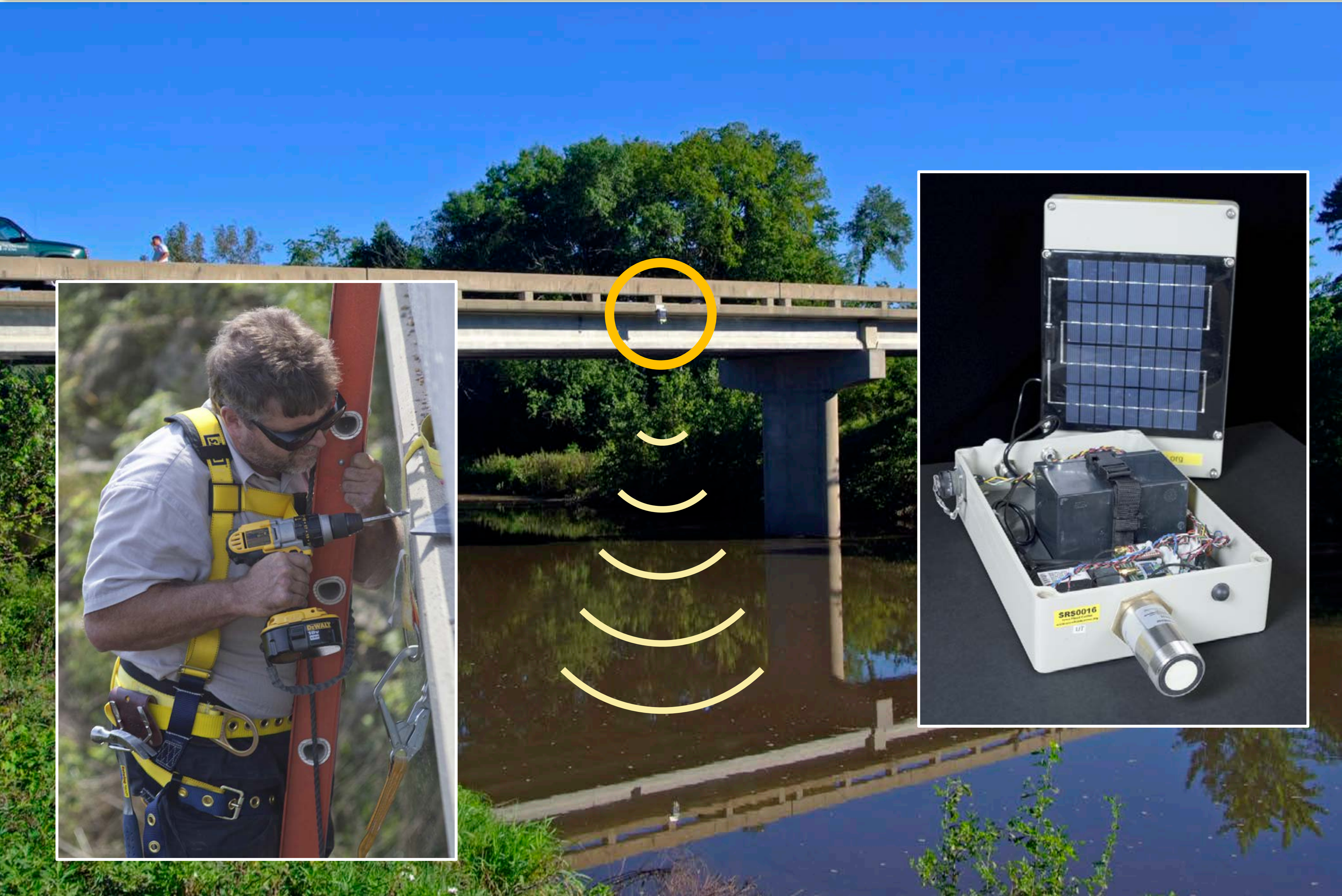
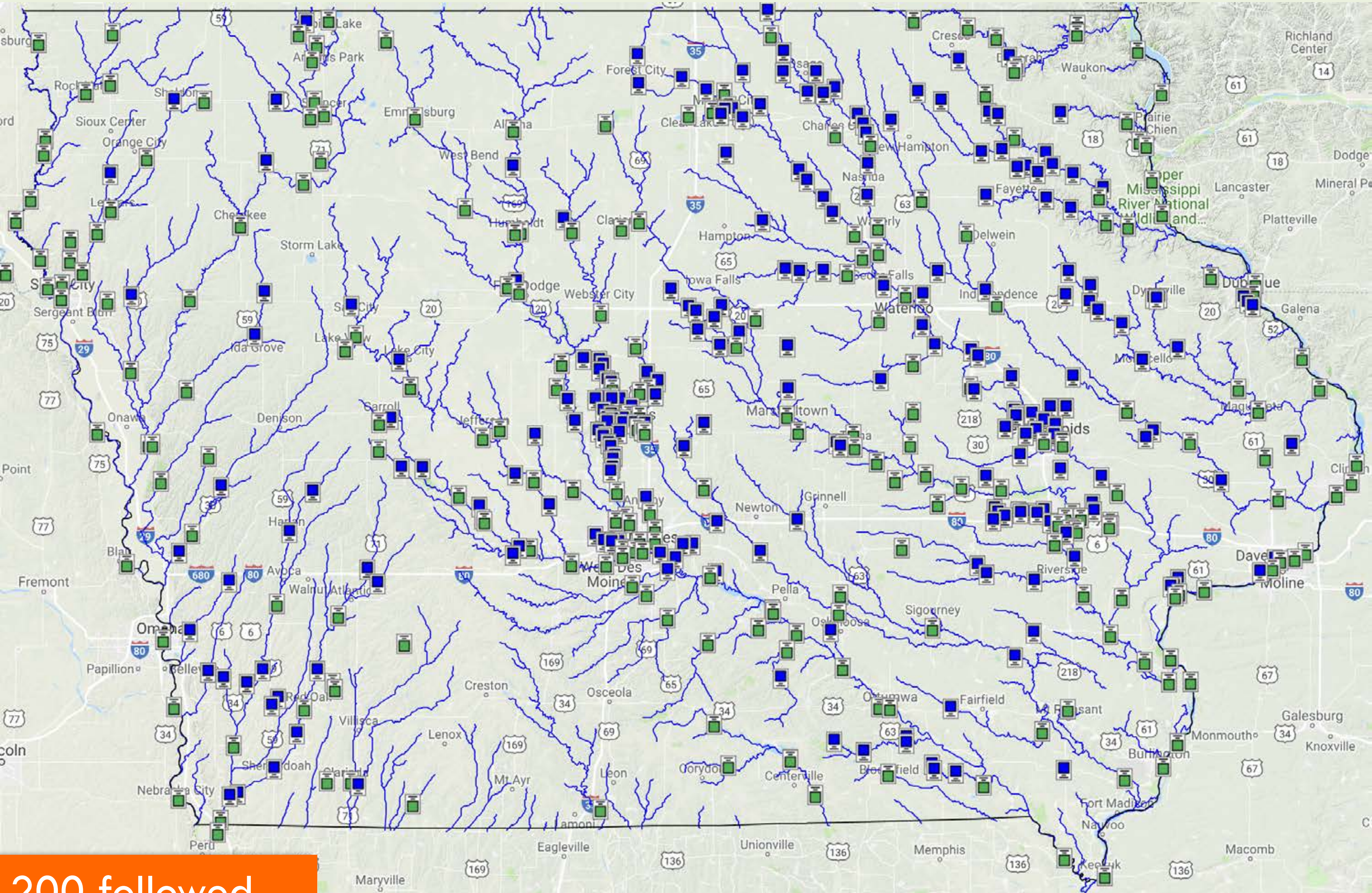
# Flood Monitoring

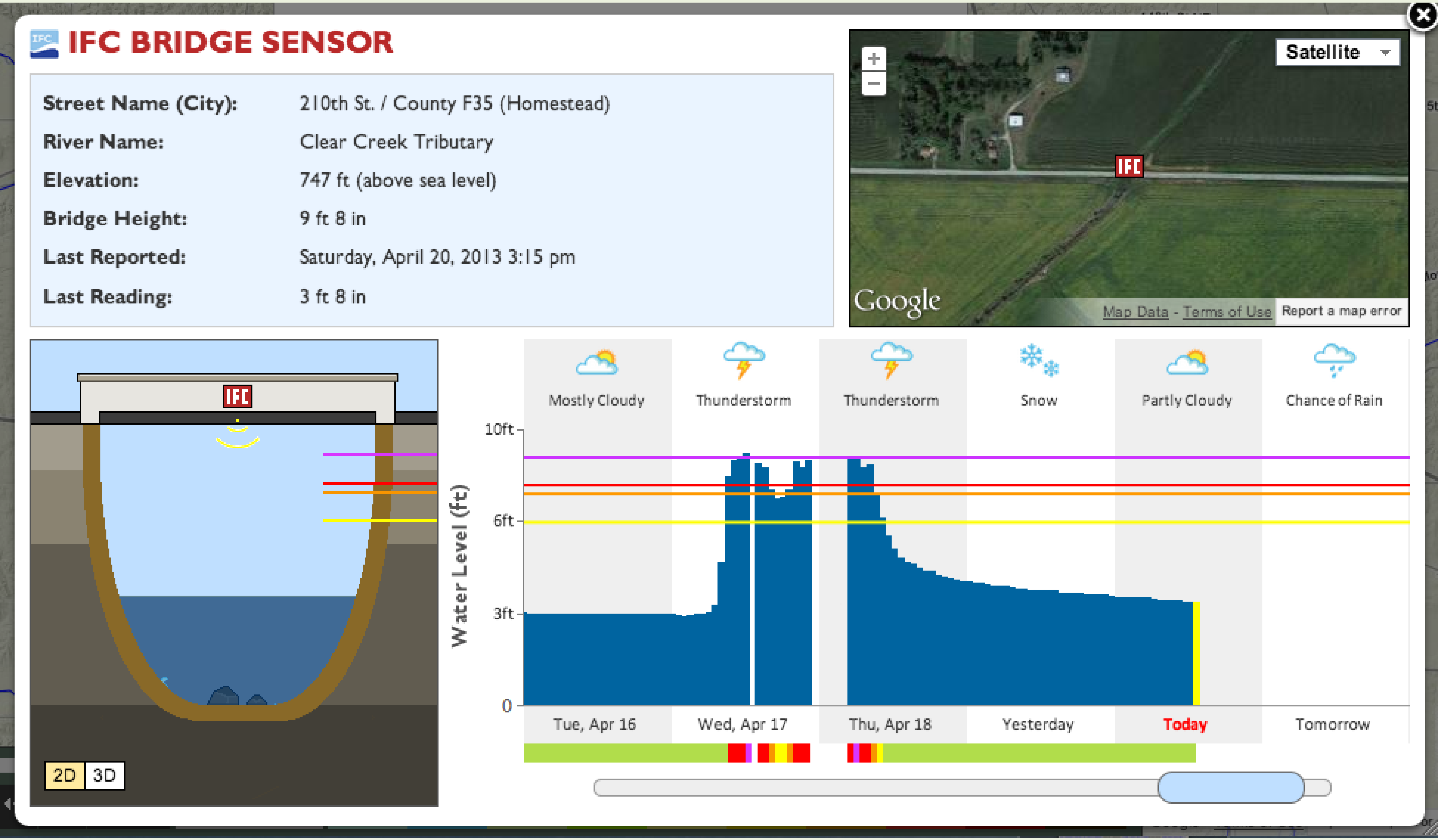
# First 50 bridge sensors…

Summer 2010

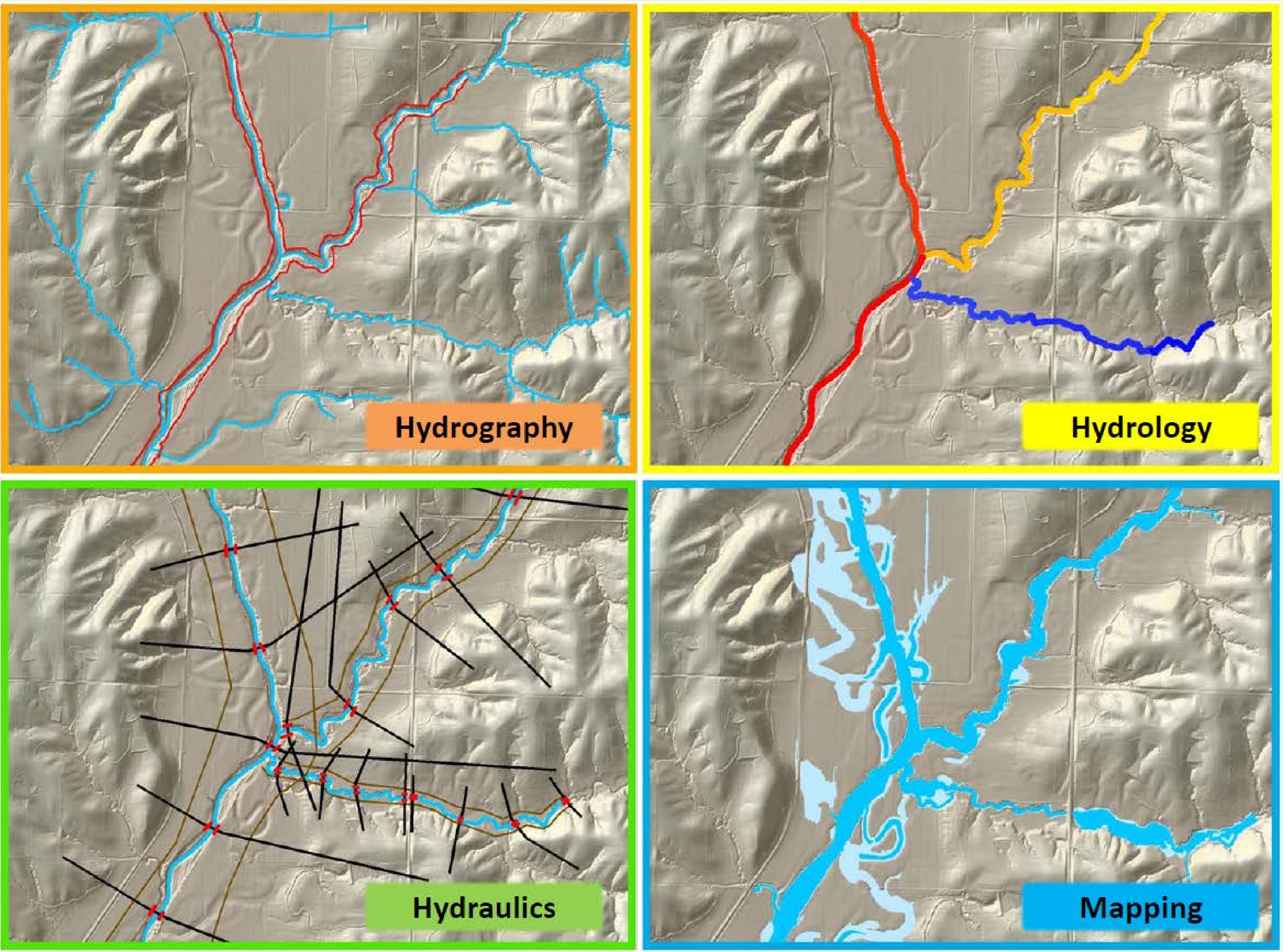




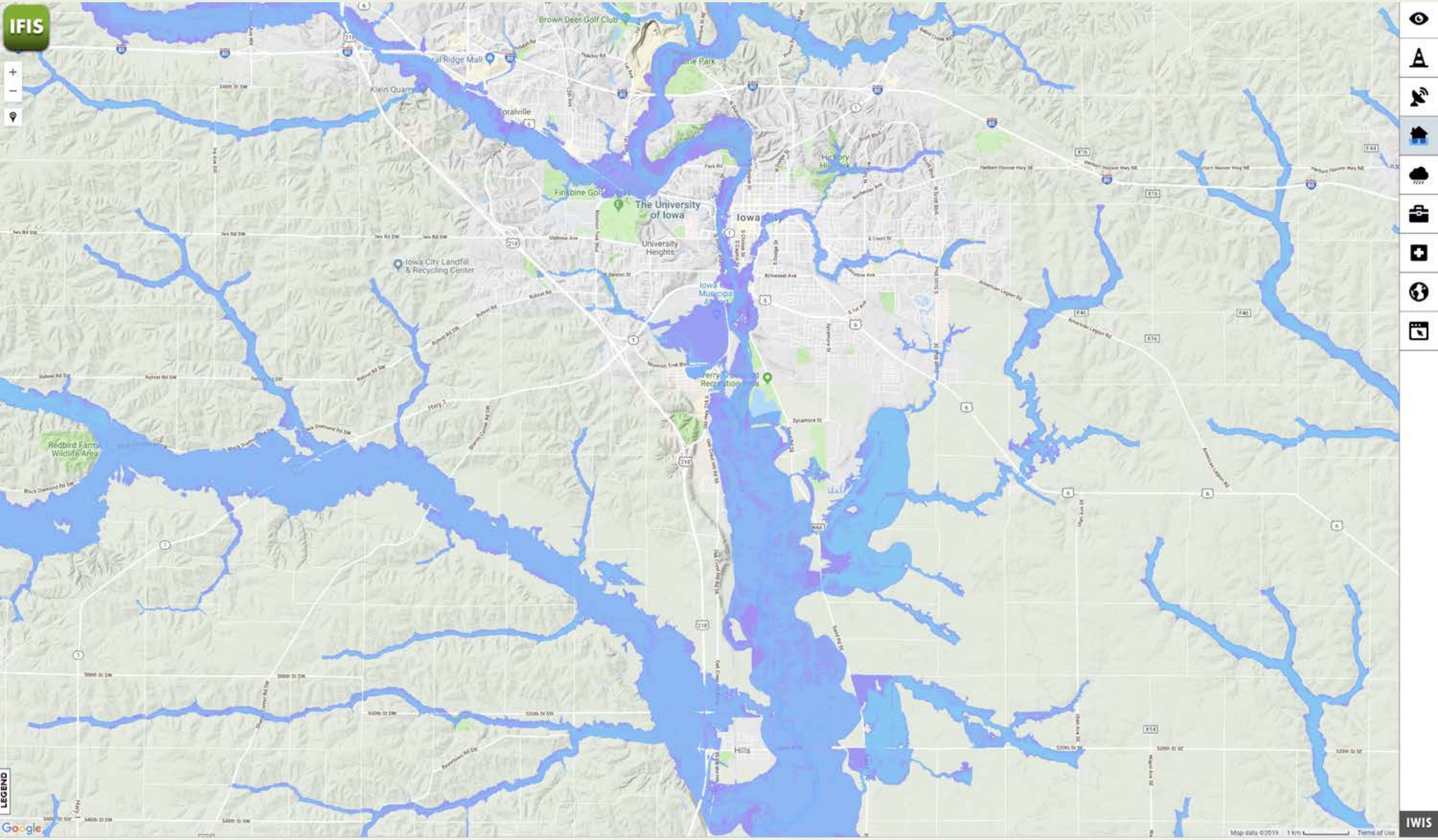

200 followed

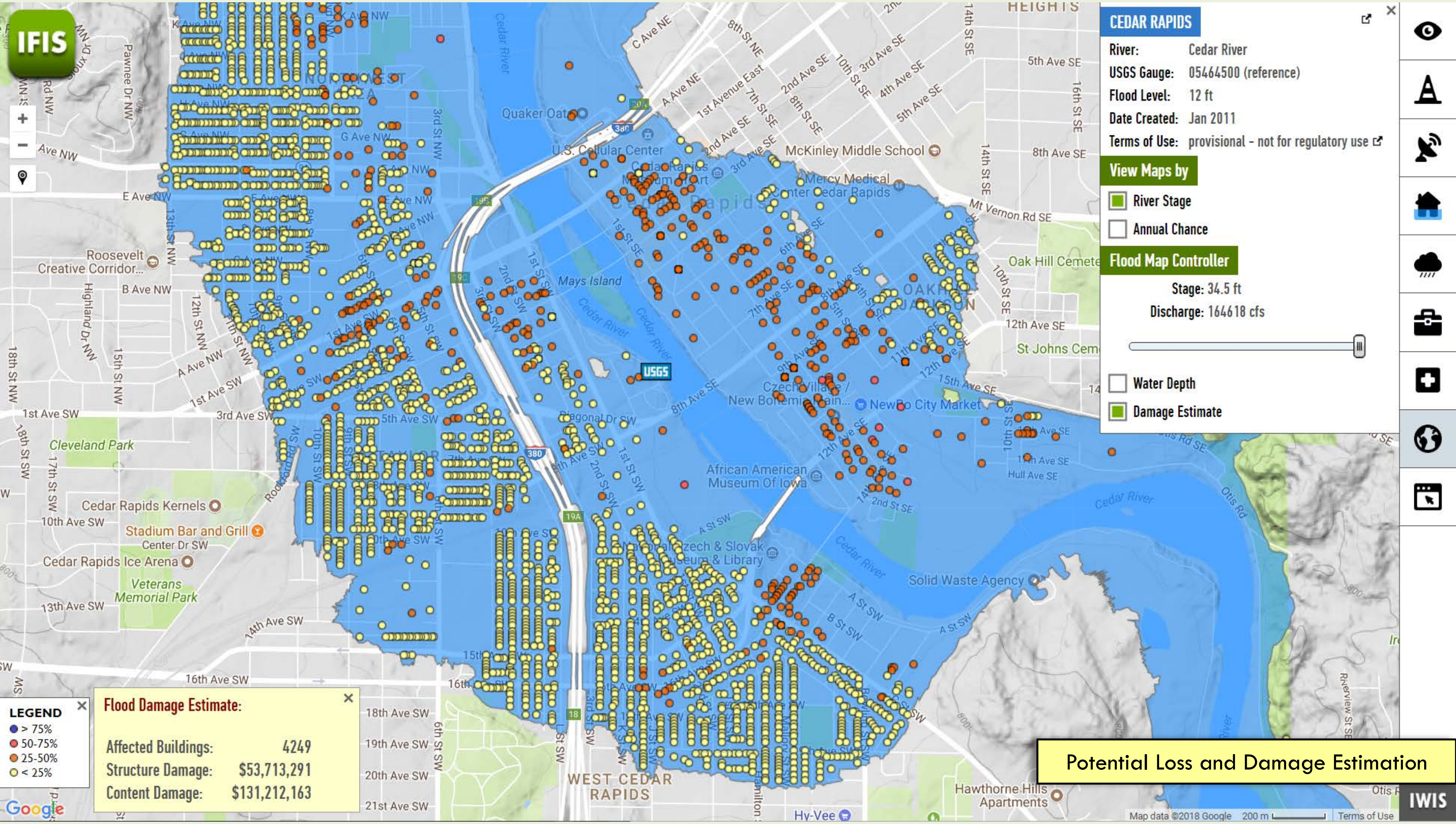

IFC BRIDGE SENSOR
Street Name (City): 210th St. / County F35 (Homestead)
River Name: Clear Creek Tributary
Elevation: 747 ft (above sea level)
Bridge Height: 9 ft 8 in
Last Reported: Saturday, April 20, 2013 3:15 pm
Last Reading: 3 ft 8 in
Satellite
IFC
Google
Map Data - Terms of Use
Report a map error
IFC
2D
3D
Mostly Cloudy
Thunderstorm
Thunderstorm
Snow
Partly Cloudy
Chance of Rain
Water Level (ft)
10ft
6ft
3ft
0
Tue, Apr 16
Wed, Apr 17
Thu, Apr 18
Yesterday
Today
Tomorrow

# Flood Mapping


Hydrography
Hydrology
Hydraulics
Mapping

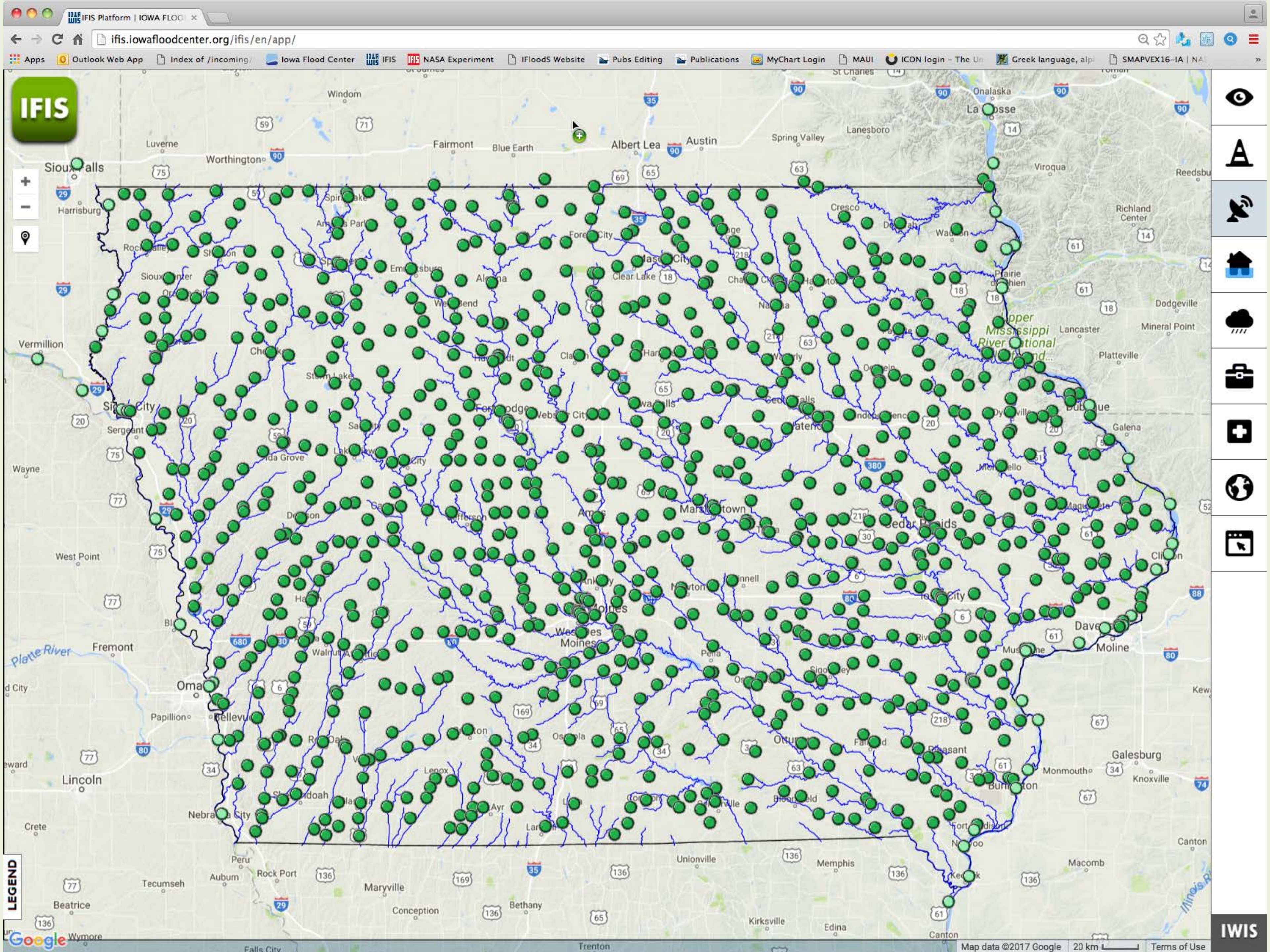
# 500-year flood inundation map

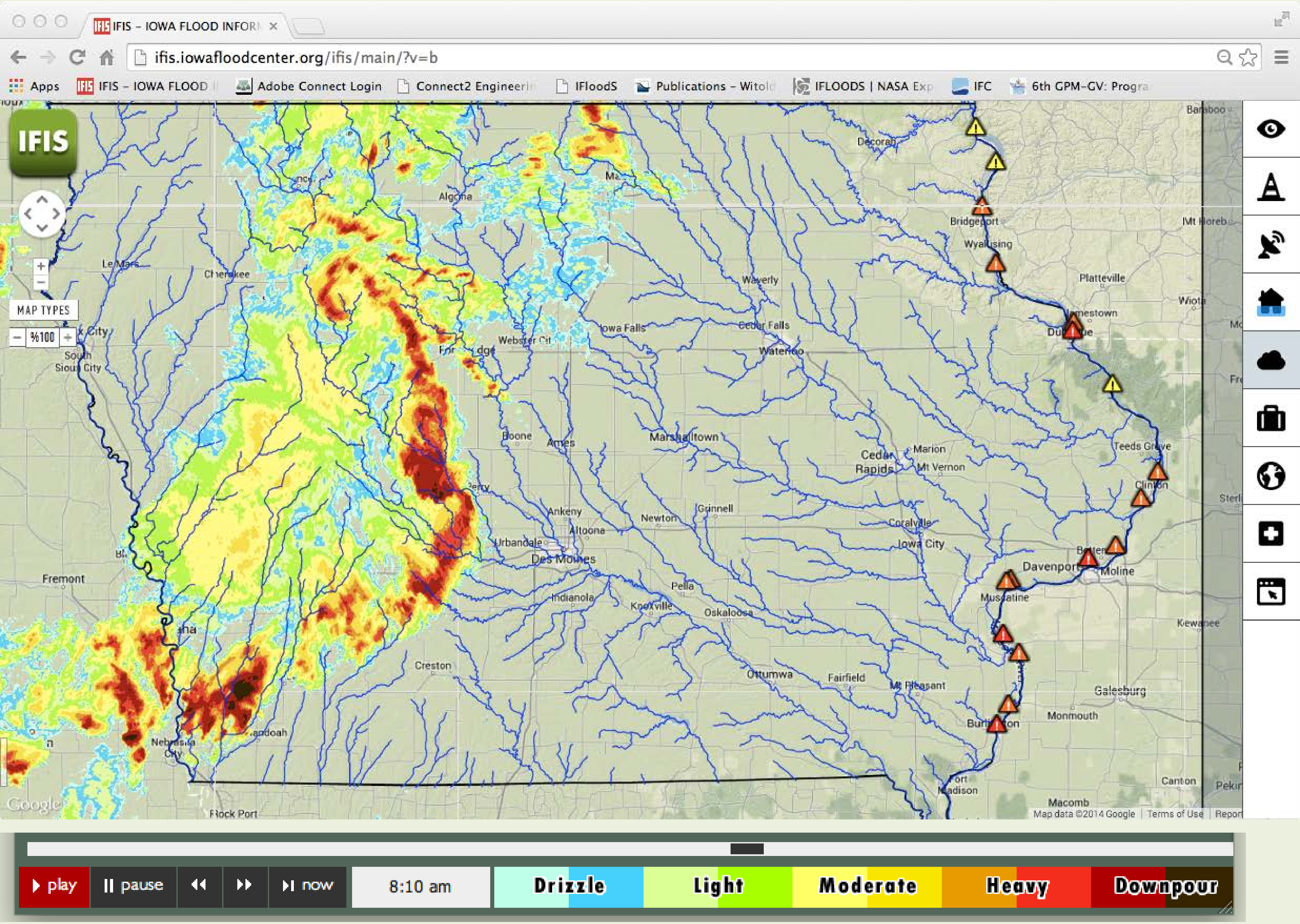


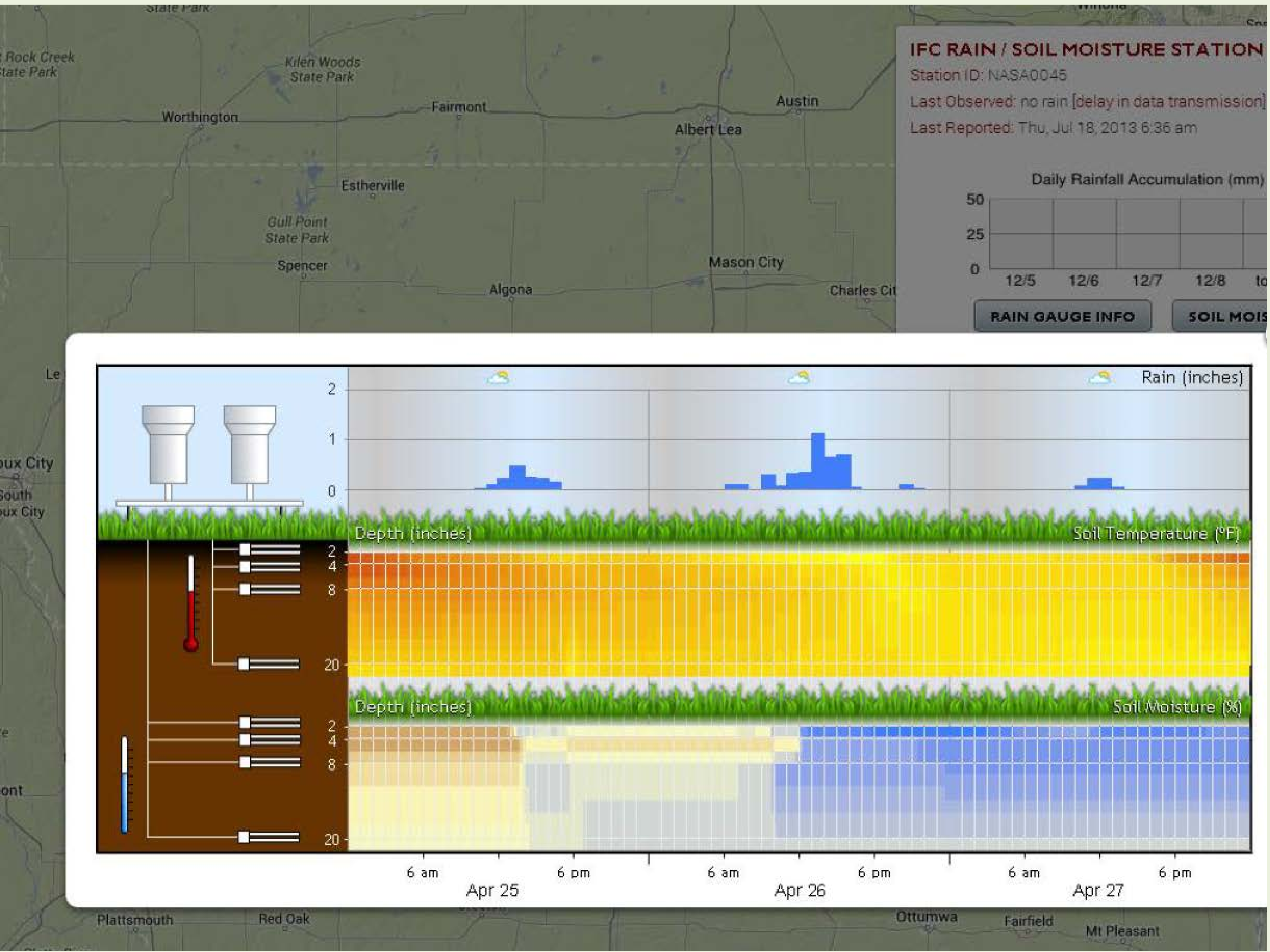



Potential Loss and Damage Estimation

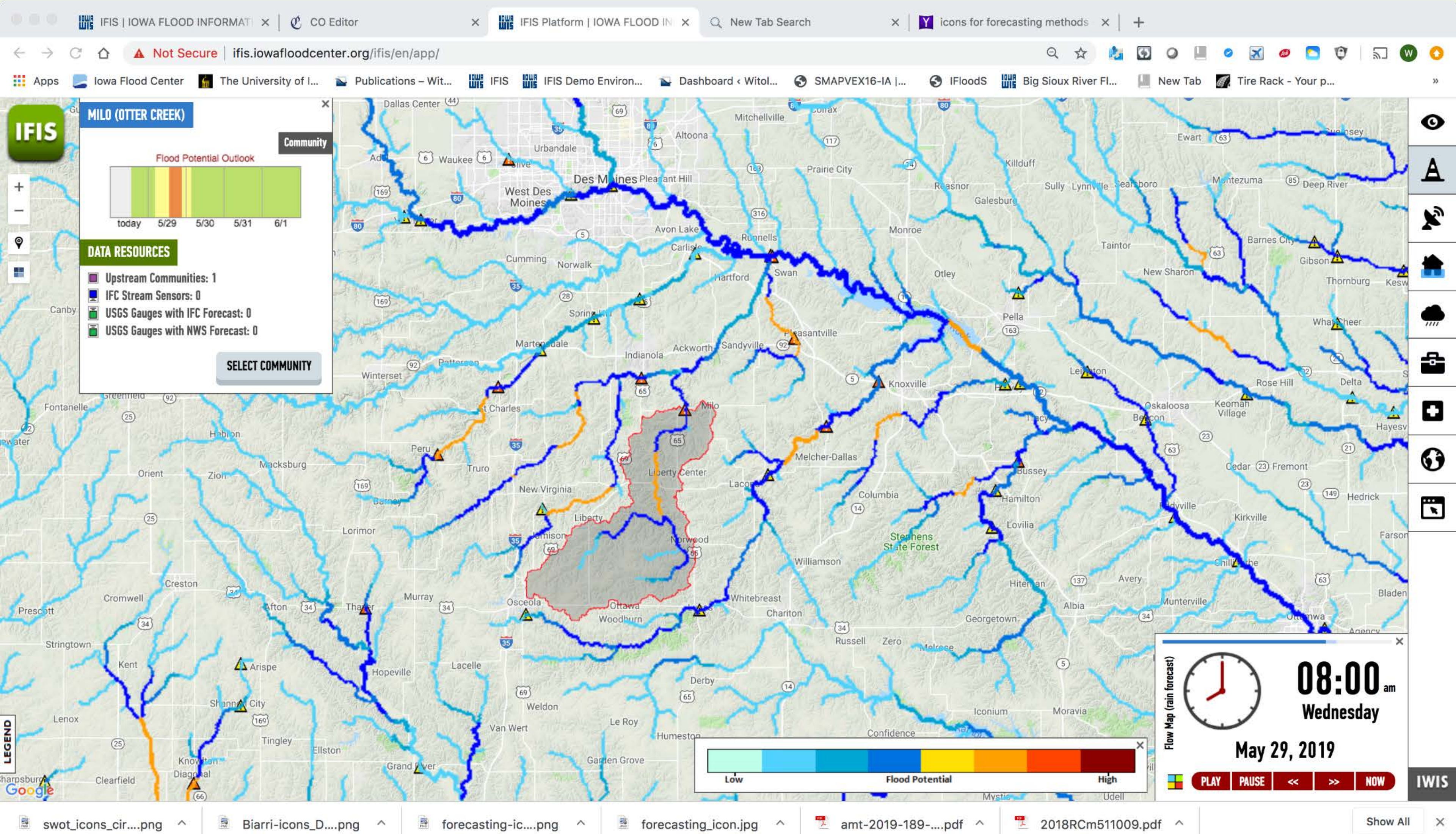
# Flood Forecasting


IFIS Platform | IOWA FLOO
ifis.iowafloodcenter.org/ifis/en/app/
Apps
Outlook Web App
Index of /incoming
Iowa Flood Center
IFIS
NASA Experiment
IFloodS Website
Pubs Editing
Publications
MyChart Login
MAUI
ICON login - The Ur
Greek language, alp
SMAPVEX16-IA | NA
IFIS
Windom
Luverne
Worthington
Fairmont
Blue Earth
Albert Lea
Austin
Spring Valley
Lanesboro
Onalaska
Viroqua
Reedsbu
Richland Center
Harrisburg
Cresco
Clear Lake
Dodgeville
Mineral Point
Lancaster
Platteville
Vermillion
Galena
Wayne
West Point
Fremont
Platte River
Papillion
Lincoln
Crete
Moline
Galesburg
Monmouth
Knoxville
Kew
Canton
Macomb
Memphis
Unionville
Peru
Auburn
Rock Port
Tecumseh
Maryville
Beatrice
Conception
Bethany
Kirksville
Edina
Wymore
Trenton
Falls City
LEGEND
Map data ©2017 Google
20 km
Terms of Use
IWIS

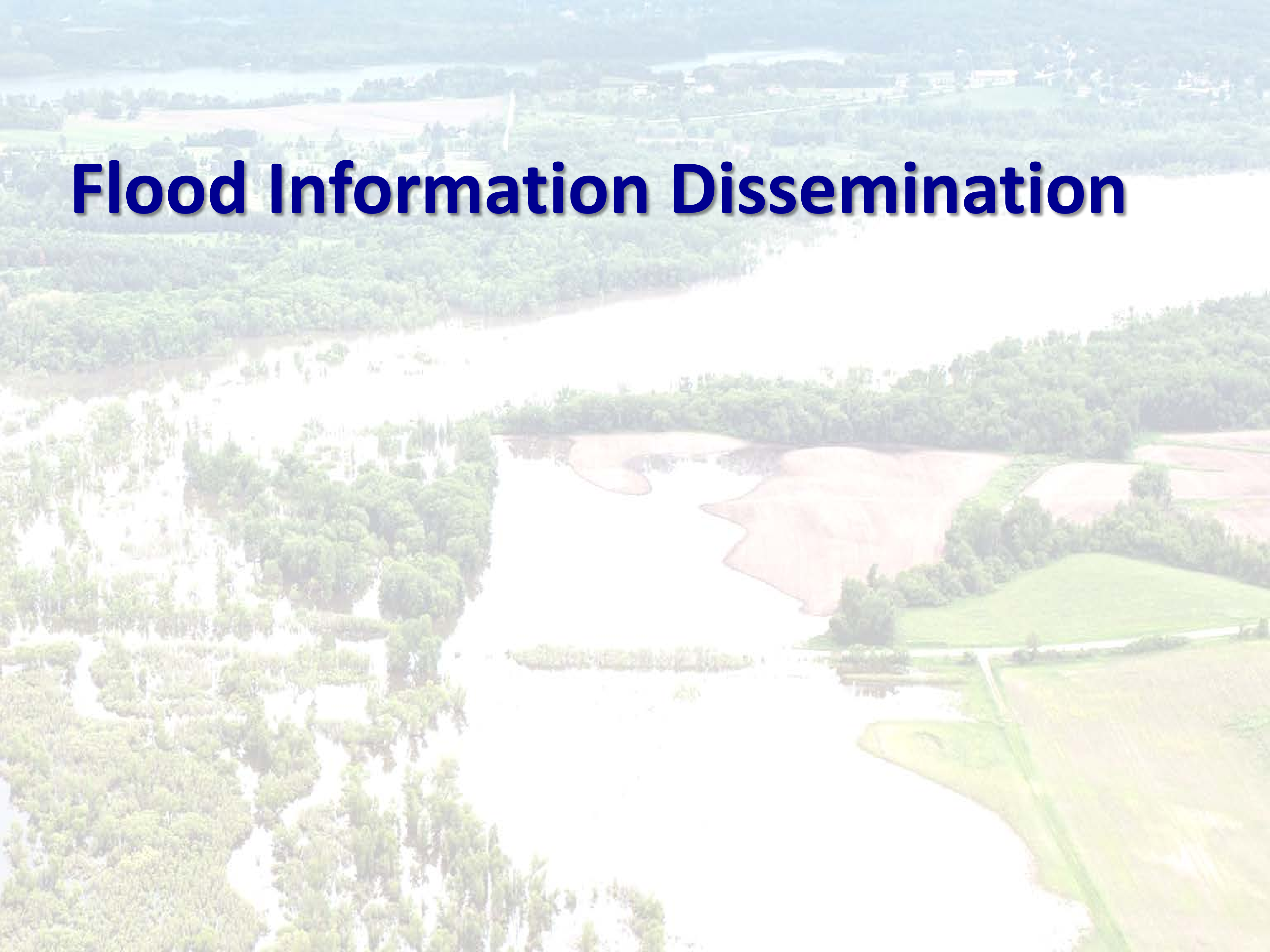

IFIS - IOWA FLOOD INFOR
ifis.iowafloodcenter.org/ifis/main/?v=b
Apps
IFIS - IOWA FLOOD
Adobe Connect Login
Connect2 Engineerin
IFloodS
Publications - Witold
IFLOODS | NASA Exp
IFC
6th GPM-GV: Progra
IFIS
MAP TYPES
%100
Decorah
Algona
Bridgeport
Wyalusing
Le Mars
Cherokee
Waverly
Platteville
Jamestown
Iowa Falls
Cedar Falls
Waterloo
Webster City
Sioux City
Boone
Ames
Marshalltown
Cedar Rapids
Marion
Mt Vernon
Teeds Grove
Perry
Ankeny
Altoona
Newton
Grinnell
Clinton
Coralville
Iowa City
Urbandale
Des Moines
Davenport
Moline
Muscatine
Fremont
Indianola
Pella
Knoxville
Oskaloosa
Kewanee
Creston
Ottumwa
Fairfield
Mt Pleasant
Galesburg
Monmouth
Burlington
Nebraska City
Fort Madison
Canton
Macomb
Rock Port
Map data ©2014 Google
Terms of Use
Report
play
pause
now
8:10 am
Drizzle
Light
Moderate
Heavy
Downpour



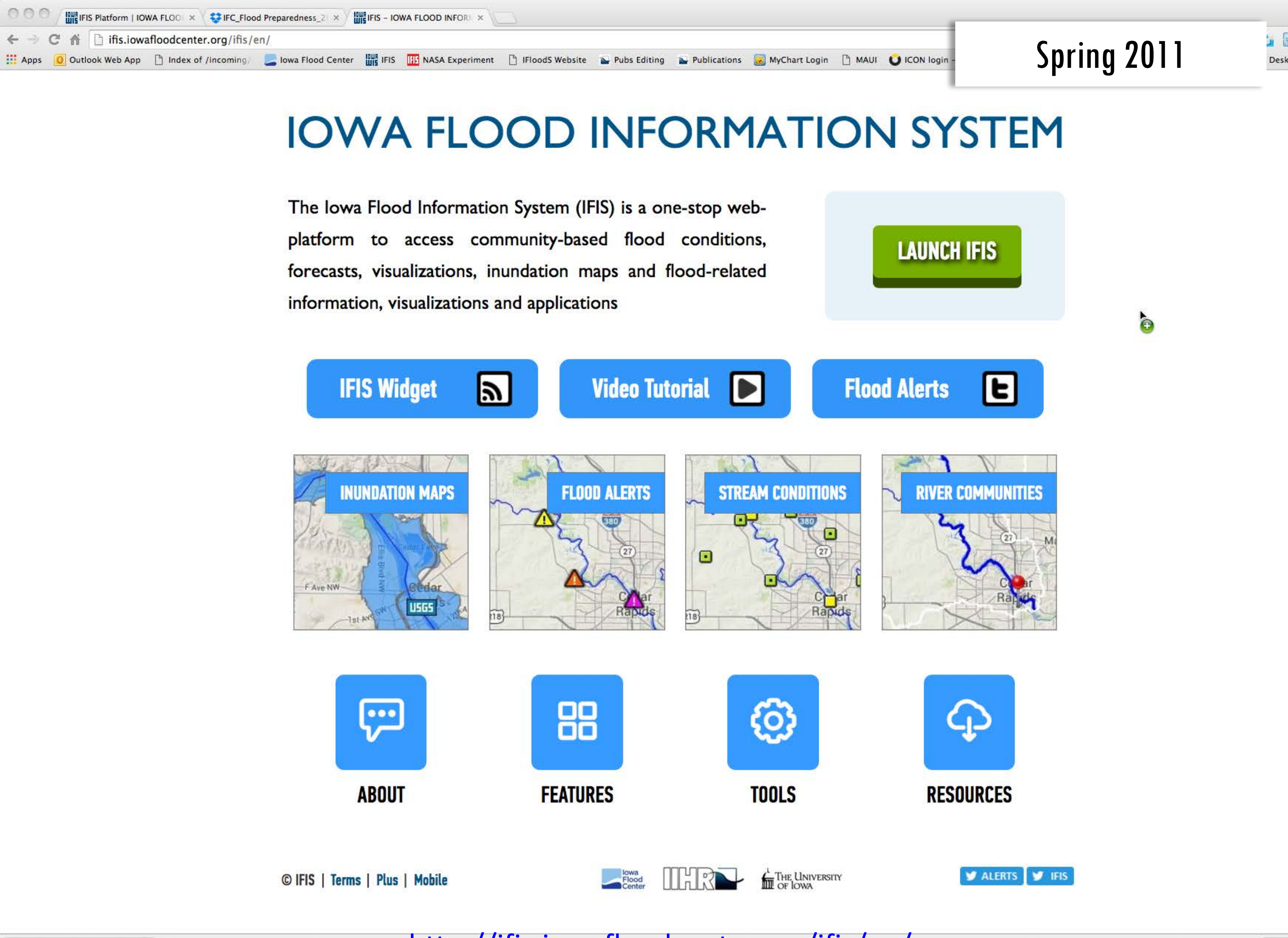
IFC RAIN / SOIL MOISTURE STATION
Station ID: NASA0045
Last Observed: no rain [delay in data transmission]
Last Reported: Thu, Jul 18, 2013 6:36 am
Daily Rainfall Accumulation (mm)
RAIN GAUGE INFO
Rain (inches)
Depth (inches)
Soil Temperature (°F)
Depth (inches)
Soil Moisture (%)
Apr 25
Apr 26
Apr 27
6 am
6 pm
Worthington
Fairmont
Albert Lea
Austin
Estherville
Spencer
Algona
Mason City
Kilen Woods State Park
Gull Point State Park
Plattsmouth
Red Oak
Ottumwa
Fairfield
Mt Pleasant


IFIS Platform | IOWA FLOOD IN
ifis.iowafloodcenter.org/ifis/en/app/
IFIS
MILO (OTTER CREEK)
Community
Flood Potential Outlook
today
5/29
5/30
5/31
6/1
DATA RESOURCES
Upstream Communities: 1
IFC Stream Sensors: 0
USGS Gauges with IFC Forecast: 0
USGS Gauges with NWS Forecast: 0
SELECT COMMUNITY
Low
Flood Potential
High
Flow Map (rain forecast)
08:00 am
Wednesday
May 29, 2019
PLAY
PAUSE
<<
>>
NOW
IWIS
LEGEND

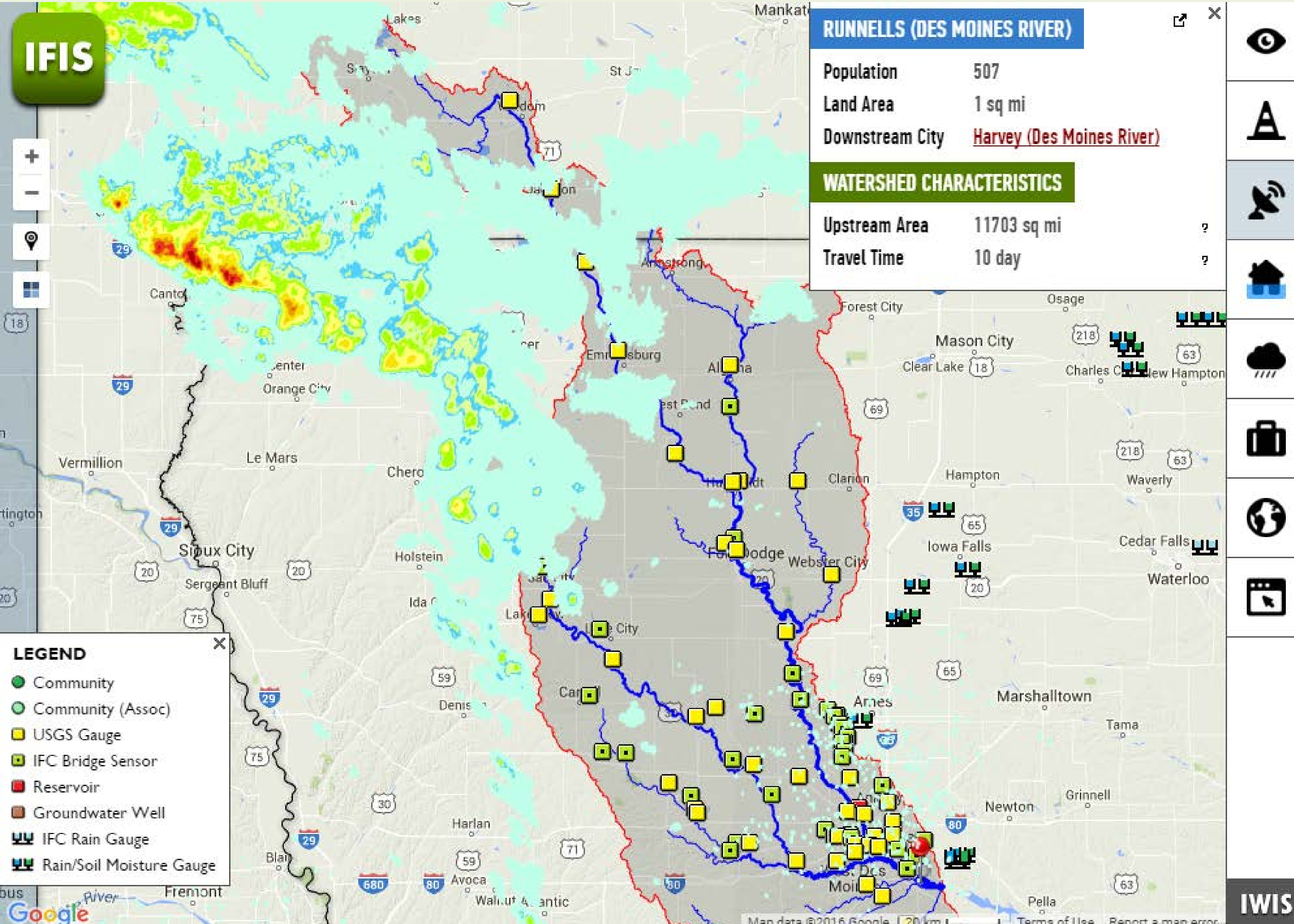
# Flood Information Dissemination



Spring 2011




http://ifis.iowafloodcenter.org/ifis/en/


IFIS
RUNNELLS (DES MOINES RIVER)
Population 507
Land Area 1 sq mi
Downstream City Harvey (Des Moines River)
WATERSHED CHARACTERISTICS
Upstream Area 11703 sq mi
Travel Time 10 day
LEGEND
Community
Community (Assoc)
USGS Gauge
IFC Bridge Sensor
Reservoir
Groundwater Well
IFC Rain Gauge
Rain/Soil Moisture Gauge
Mason City
Clear Lake
Forest City
Osage
Charles City
New Hampton
Hampton
Waverly
Clarion
Iowa Falls
Cedar Falls
Waterloo
Webster City
Ames
Marshalltown
Tama
Newton
Grinnell
Pella
Sioux City
Sergeant Bluff
Le Mars
Vermillion
Orange City
Holstein
Harlan
Avoca
Fremont
Armstrong
Osage
IWIS
Map data ©2016 Google
20 km
Terms of Use
Report a map error

US DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

NASA

USGS
science for a changing world

ars

USDA

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

NATIONAL WEATHER SERVICE

IOWA
DEPARTMENT OF
AGRICULTURE
AND LAND STEWARDSHIP

NRCS

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

US Army Corps
of Engineers®

DNR

IOWA STATE
UNIVERSITY

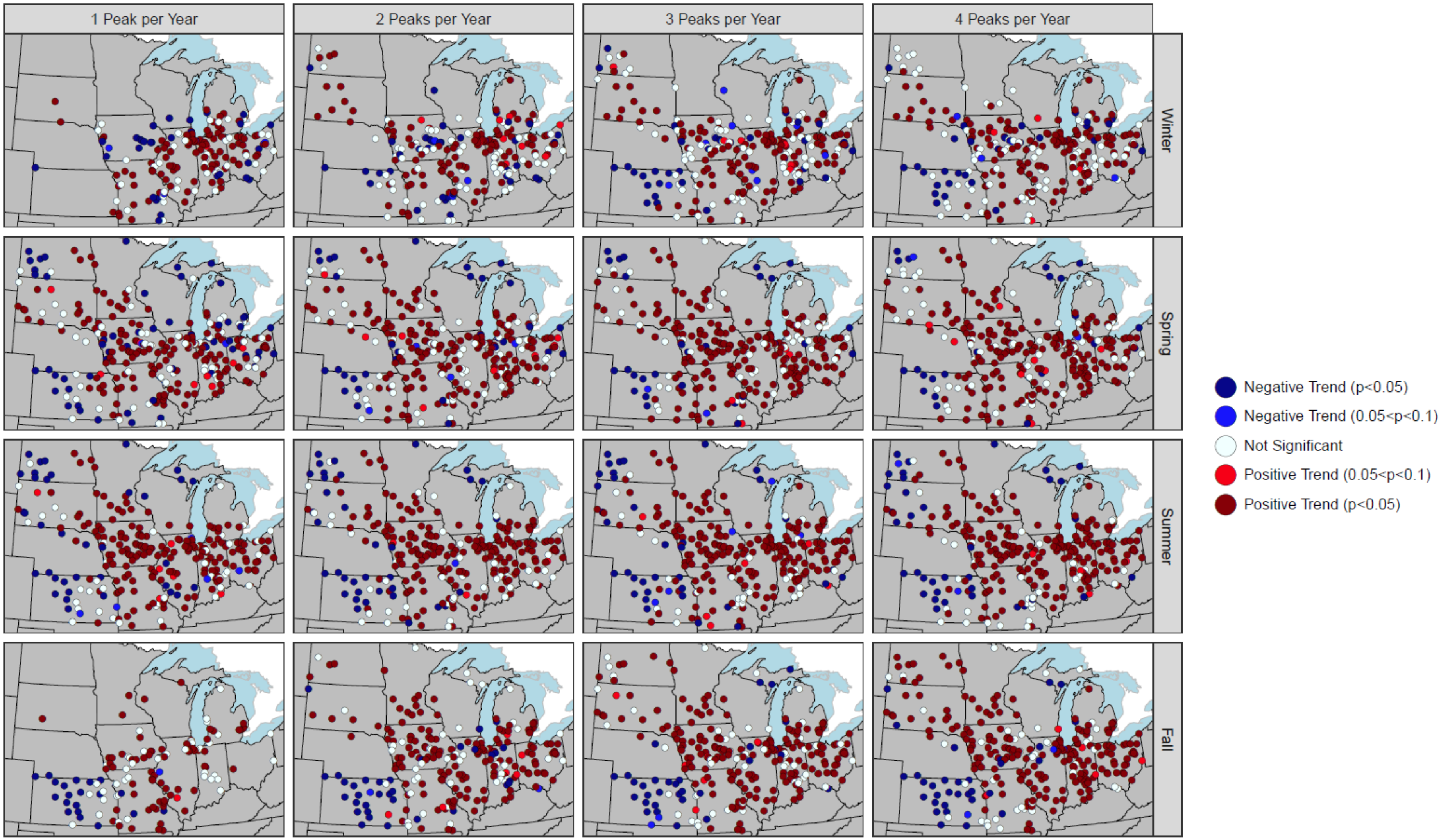
IOWA HOMELAND SECURITY AND EMERGENCY MANAGEMENT
PREVENT • PROTECT • RESPOND • RECOVER

IOWA
DOT

40 Years
CDBG
Building Better Neighborhoods

# Climate Change and Flooding in Iowa

# Overall increasing frequency in flood events rather than changes in the magnitude at the annual scale





Mallakpour, I., and G. Villarini, The changing nature of flooding across the central United States, *Nature Climate Change*, 5, 250-254, 2015.

Neri, A., G. Villarini, L. Slater, and F. Napolitano, On the statistical attribution of the frequency of flood events across the U.S. Midwest, *Advances in Water Resources*, 127, 225-236, 2019.

# How is flooding in Iowa projected to change under global warming?

High Resolution Climate Change simulation (source NCAR).

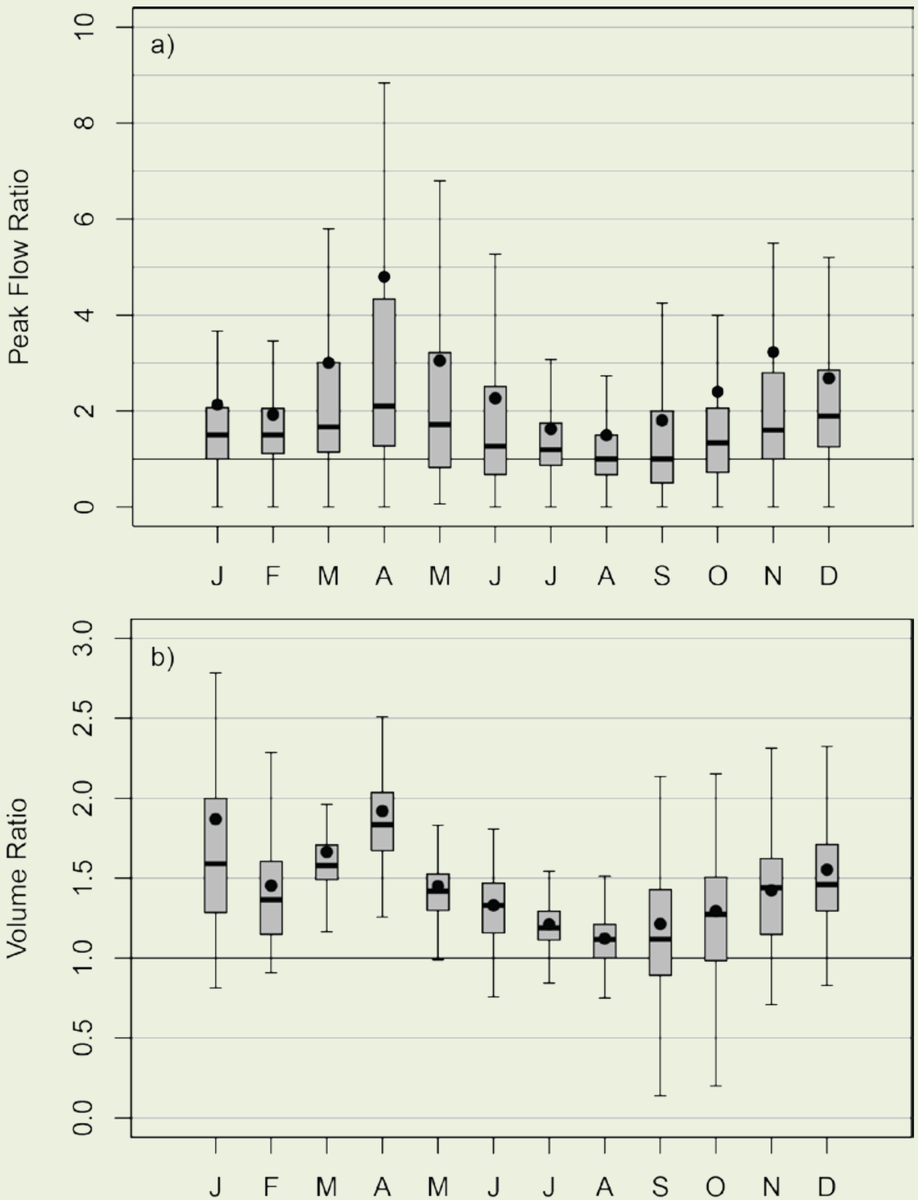
- 13 years simulations (October 2000 to September 2013)
- **Retrospective/Control Experiment (CTRL)**: reproduce the statistics (variability and mean state) of the current climate. Forced with ERA-Interim reanalysis data.
- **Pseudo-global warming experiment (PGW):** Perturbation or climate sensitivity experiment; it assumes that the current climate weather reoccurs under future climate conditions.

$$\Delta\, \text{CMIP5}_{\text{RCP8.5}} = \text{CMIP5}_{2071-2100} - \text{CMIP5}_{1976-2005}$$

$$\text{WRF}_{\text{input}} = \text{ERA-Interim} + \Delta\, \text{CMIP5}_{\text{RCP8.5}}$$

For the hydrologic simulations we used the Hillslope-Link Model (HLM) developed by the Iowa Flood Center

# Future discharge and floods in Iowa are projected to increase much more than precipitation extremes




Transition from snow to rainfall and increase in precipitation are expected to lead to a doubling of peak flows in spring

Confidential.
Do not distribute


Iowa
Fields of opportunities
Thank You!

UNIVERSITY OF TEXAS ARLINGTON

Tran-SET

Tran-SET Webinar

# Real-Time Early Detection and Monitoring of Flooding Using Low-Cost Highly Sensitivity Ultrasound Sensing of Water Level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Univ. of Texas at Arlington

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817 – 691 - 4397

Dr. Seongjin Noh, Dr. Dong-Jun Seo, Sanggoo Kang, Dafnik David, Muil Yang, and Yin Chao Wu

# Contents

# Motivation


TRINITY RIVER AT DALLAS
Universal Time (UTC)
Stage (ft)
Flow (kcfs)
Site Time (CDT)
Observed

# Motivation

Flooding at the bridge side




Urban flooding




***Example of urban flooding***

Flooding poses safety hazards to motorists, emergency and maintenance crews and may cause costly damage to transportation infrastructure and its operation. Flash flooding, in particular, causes the most flood-related deaths. According to NOAA, in 2017 alone, flash flooding also caused $60.7 billion worth of economic damage.

# Need and Goal

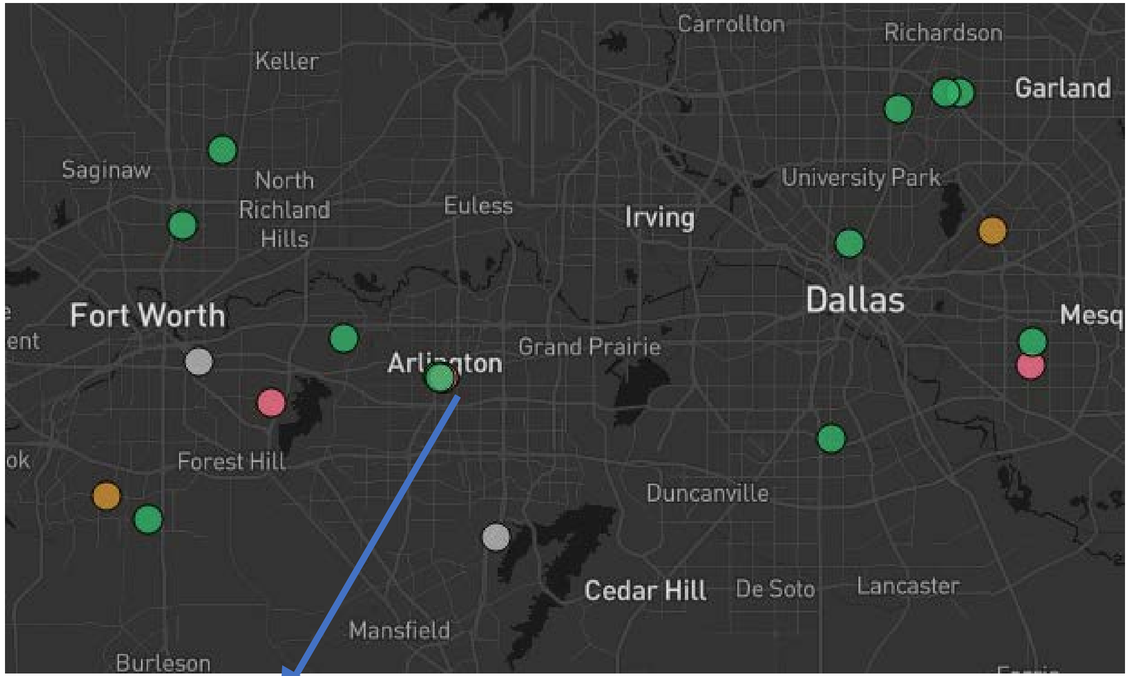
**Needs:**

- **Reliable non-contact sensor** water level detection
- **Real-time monitoring system** for efficient data transmission and storage
- Highly efficient **power-saving** unit
- Monitoring the **urban inundation and river overflow**

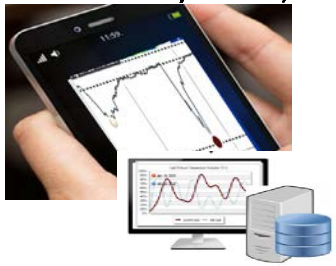
**Goal :**

Development of the **low-cost and reliable ultrasonic water level detection (UWLD)** unit for <u>monitoring urban flood inundation associated with infrastructure</u>

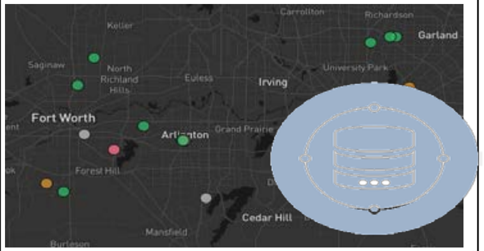
# Current System:




**Sharing and Alerting**
(mobile app and web based system)



**Managing**
(cloud service)



**Receiving**
(efficient post-process)

**Transmitting, communication**
(Satellite, Cellular, Rola)

**Sensing**

Control Main board

high capacity Battery + renewable

Power regulator

Cellular module.

Output:

UT sensor

# Objectives

**Objective 1 To develop the <u>low-cost</u> and <u>reliable</u> water level monitoring system**

1) Circuitry design for cost-effective unit (or components) (<$200) including microcontroller (MCU) and cellular module, and sensor,
2) Algorithm design for reliable system (e.g., data filtering, error fix, and sleep mode)
3) Real-time accessible user interface platform (e.g., Amazon Web Service)

**"Cost-effective unit"**

**Objective 2: To study the water level on <u>multiple target or location</u>**

1) Deploy multiple sensors on pavement and stream sides
2) Water level analysis at the different target and location (e.g., node)

**"Dual-target"**

**Objective 3 : To operate the unit in <u>power efficiency</u>**

A comparative study in power saving mode:

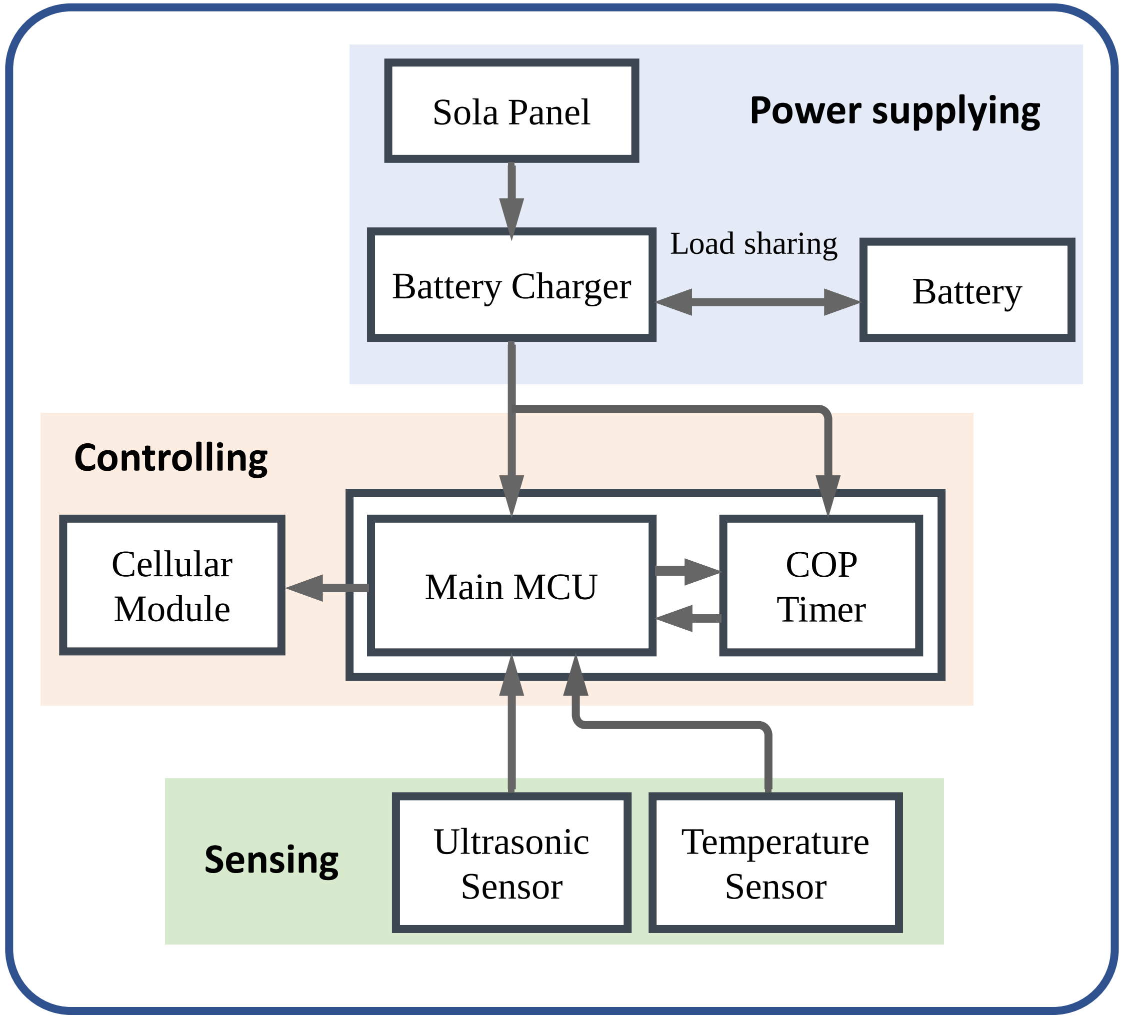
1) Computer operating properly (COP) timer
2) <u>Dual microcontroller (MCU)</u>

**"Dual-MCU"**

# Methodology

# Methodology : 1. UWLD System Development

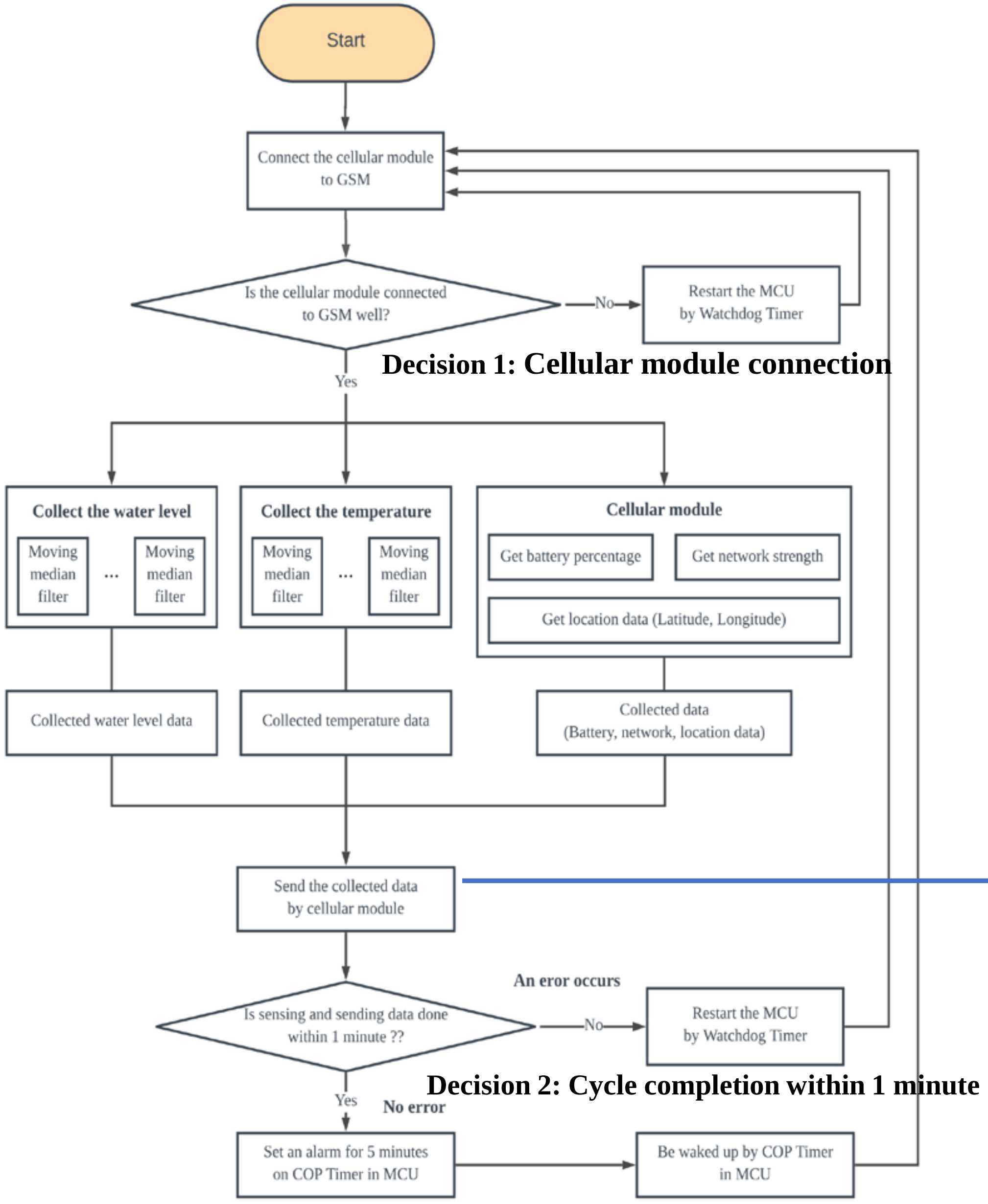
**1) Circuitry design for Low-cost and reliable**




***System representation of proposed UWLD***

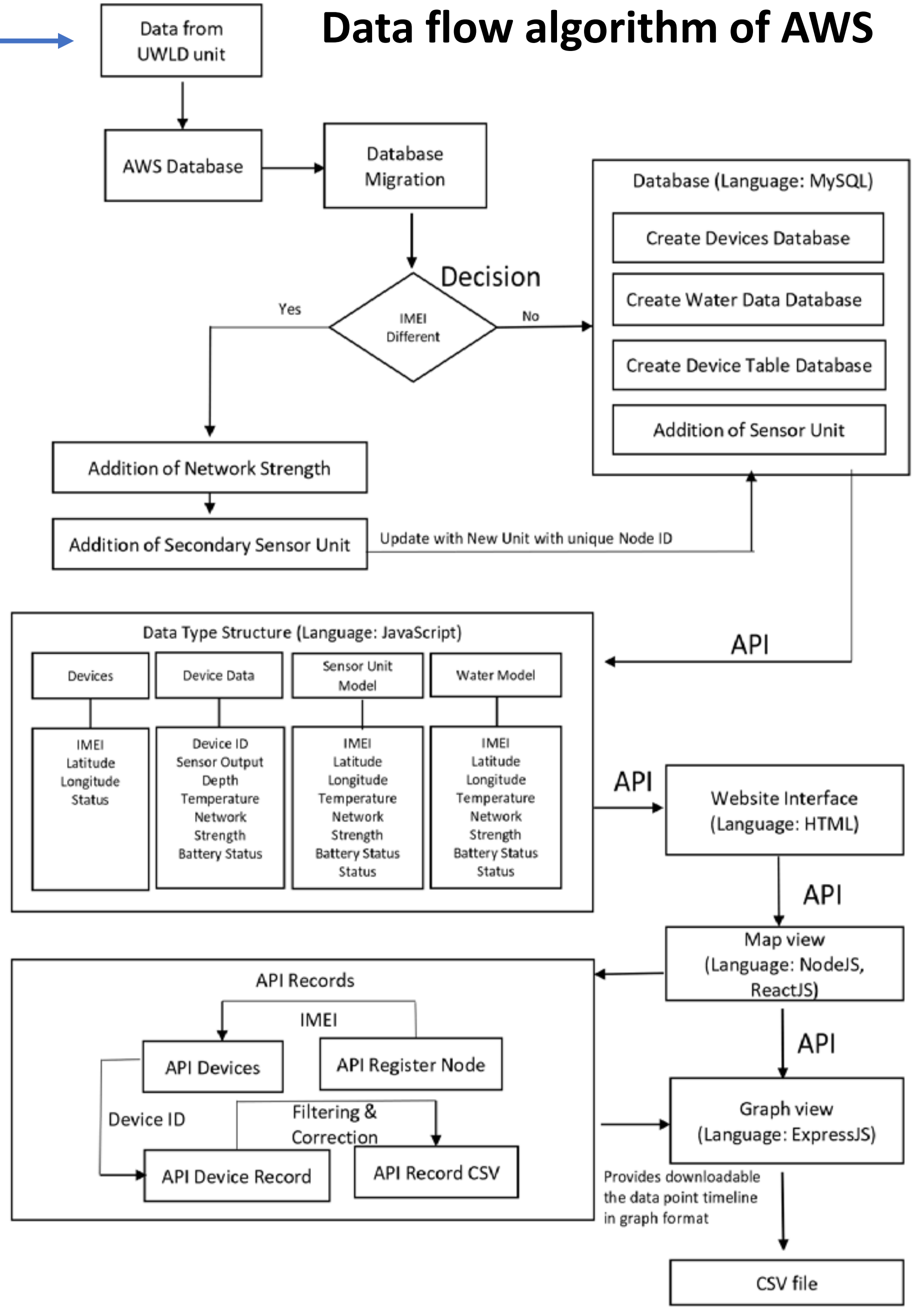
- **Power supplying, controlling, and sensing** parts are main of the unit, and each part consists of several components as shown in the figure.
- Battery charger has load sharing function that allows the **solar panel** to **charge the battery** and **supply power to the MCU and sensors simultaneously**. Charger with **load sharing function** is deployed for daytime when the solar panel produces more electricity than it is needed for operating the UWLD system.
- The **cellular module** is deployed to transfer the data collected by sensors to **AWS server** for the real-time data plotting.
- The **MCU operates and controls two sensors.**
- **Ultrasonic sensor** is deployed to calculate the distance between the sensor and the water surface. And the **temperature sensor** is deployed to increase accuracy by considering the temperature effect on sound speed.

## 2) Algorithm design for reliable system

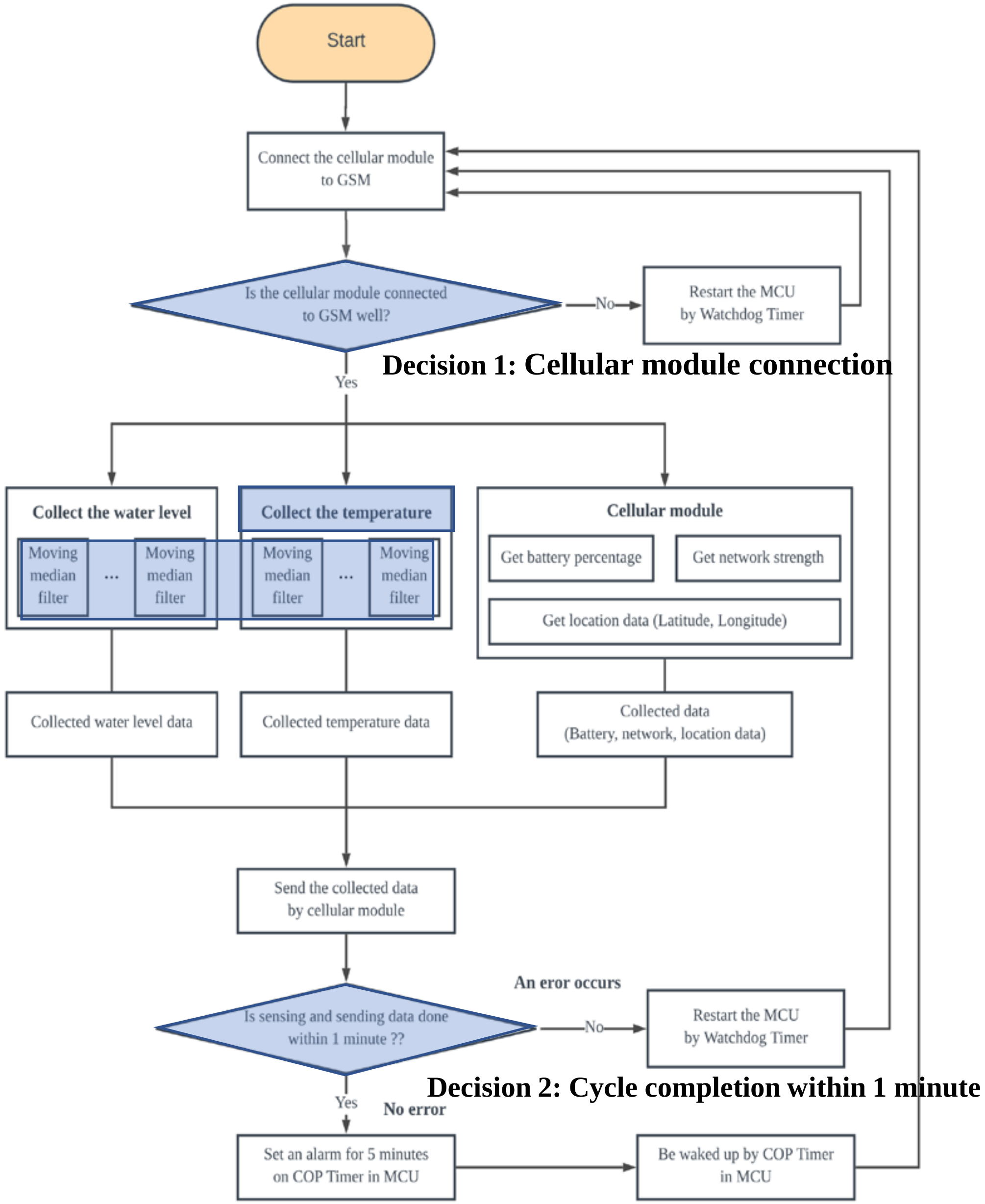



Data flow algorithm of the UWLD system

## Data flow algorithm of AWS



## 2) Algorithm design for reliable system




**Data flow algorithm of the UWLD system**

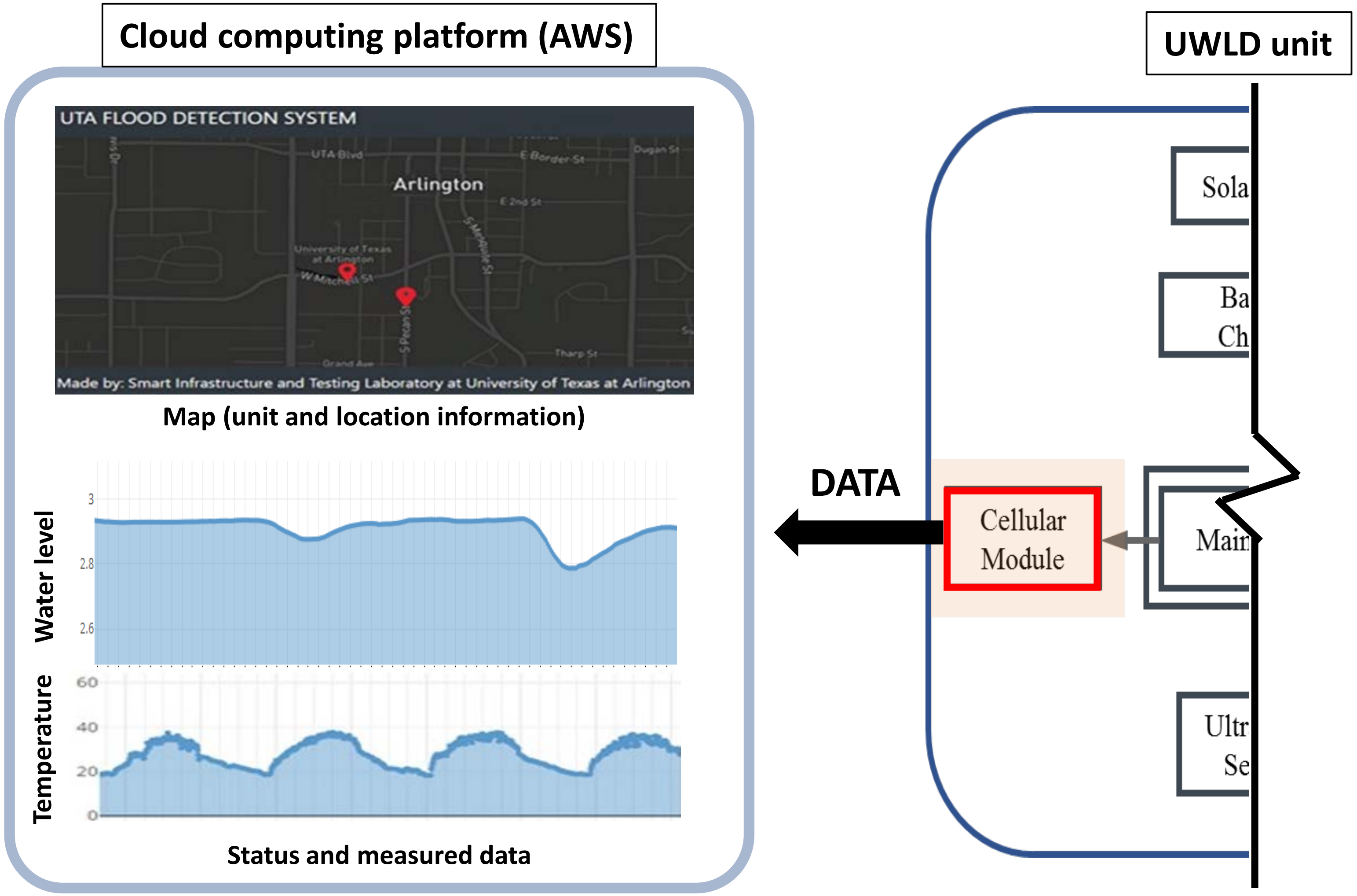
- From the flowchart, two decisions are employed for fault detection. And COP (watchdog timer) is employed for reboot when a fault is detected. The timer is normally included in Atmel's MCU to automatically reset an embedded device.

- Decision 1 in the figure is for checking whether the cellular module is connected well.

- Decision 2 is for checking the completion of one cycle of collecting and sending data within 1 minute. The one cycle is normally completed within 30 seconds, so it means an error occurs if the cycle is not completed within 1 minutes. And the watchdog timer allows rebooting the system when an error occurs.

### 3) Real-time accessible user interface platform

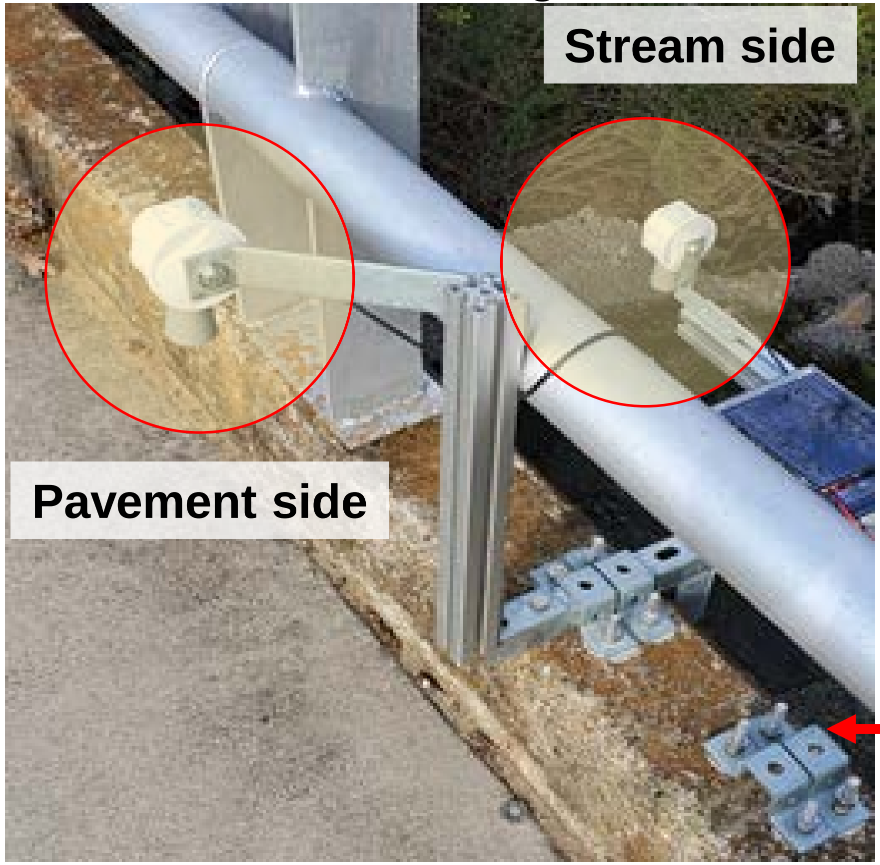
- To monitor the water level data in real-time, the online accessible cloud computing platform is used.
- DATA from the UWLD unit is transmitted to the Amazon Web Service sever via cellular module.
- The location of nodes is marked on the map with an application programming interface (API)

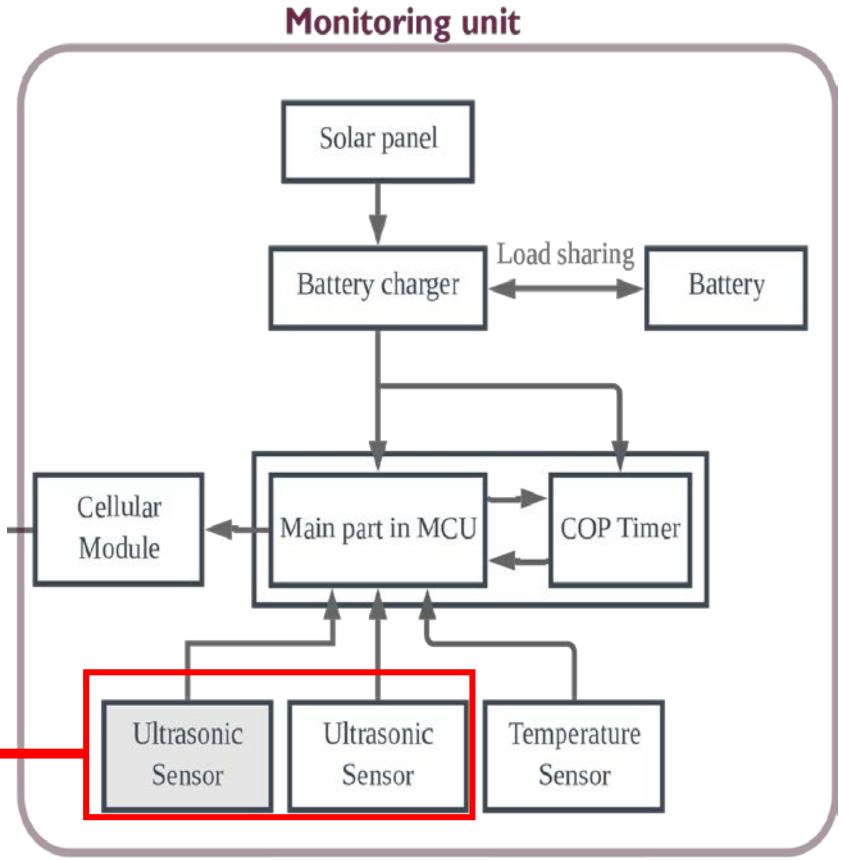


# Methodology : 2. Dual-target

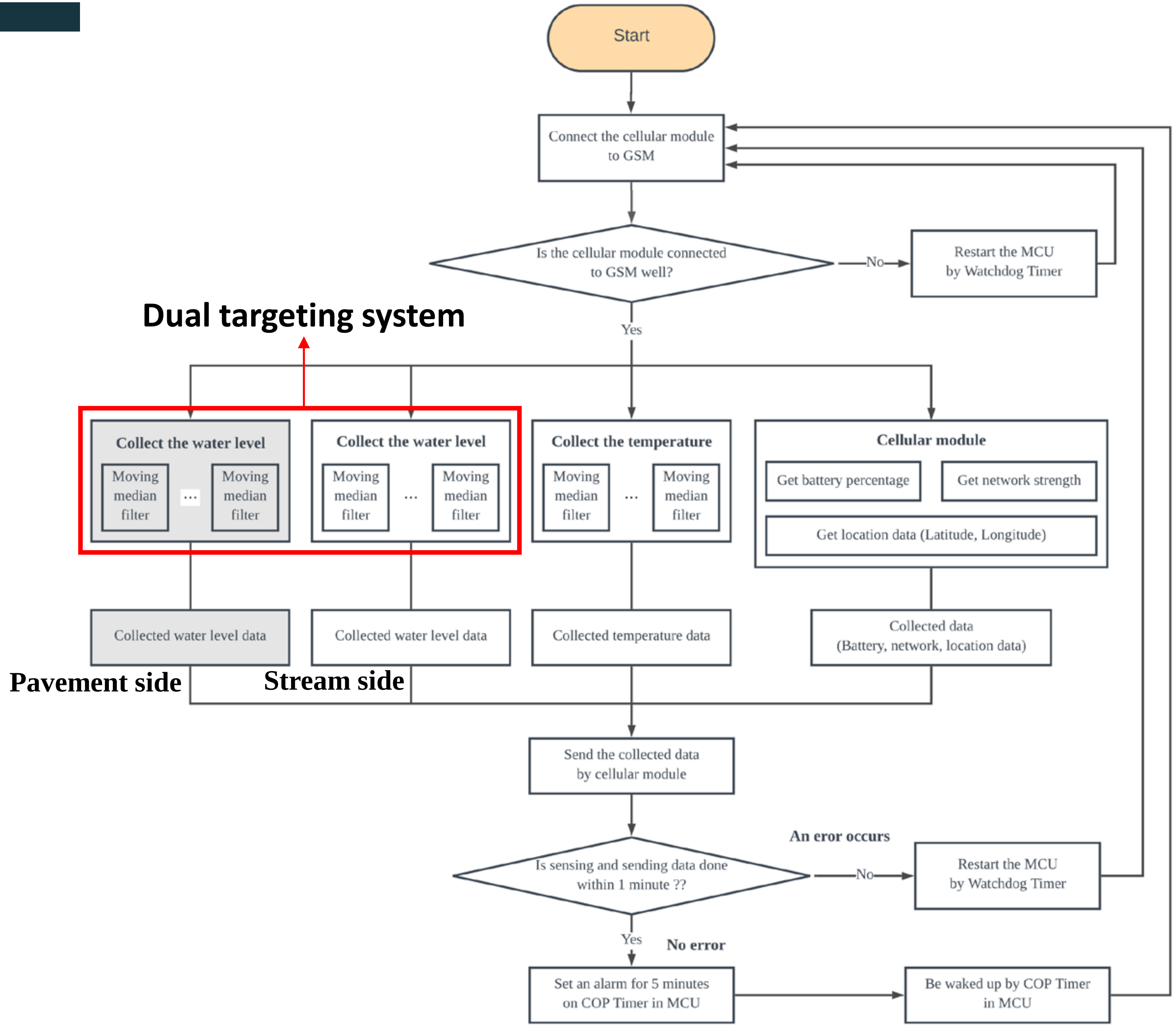
- In some cases, there is several factors (e.g., drain issue), causing urban inundation and stream overflow.
- Therefore, it is highly important to water level monitoring for **dual-targeting** both pavement and stream sides

**Dual target**




*System representation of Dual target sensing*



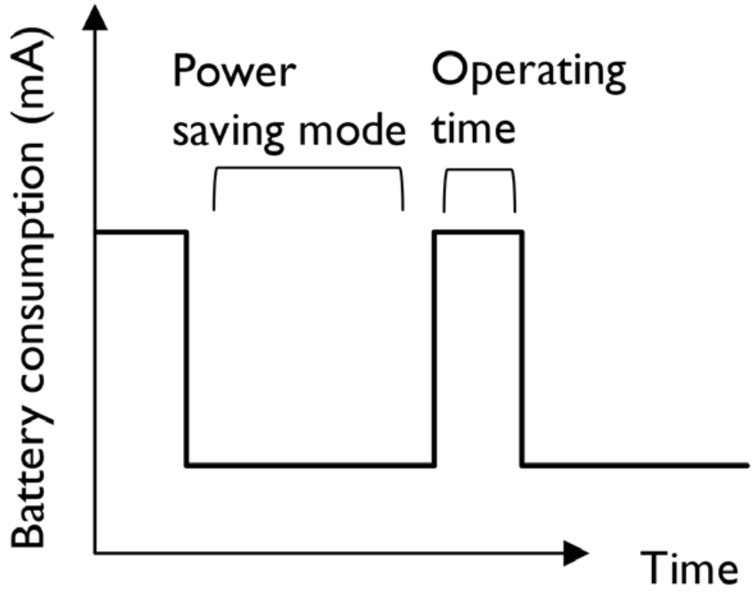

*Flowchart of UWLD system modified with dual target*

- The **additional ultrasonic distance sensor** is installed on the pavement side.
- The collected data through the moving median filter are transferred with stream side water level, temperature, and cellular module data.

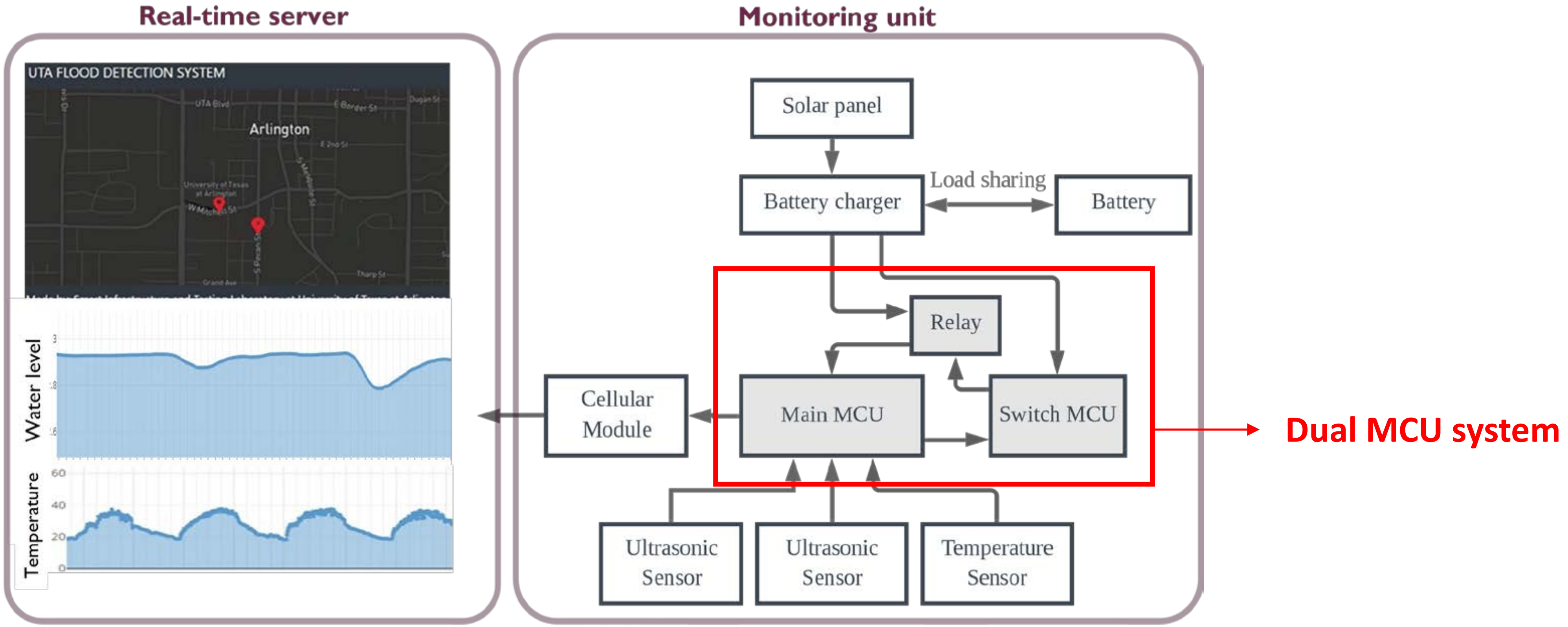
# Methodology: 3. Dual Microcontroller

- To improve the power efficiency of the unit, we performed a comparative study; 1) "Sleep-mode" using computer operating properly **(COP)** timer and 2) **dual MCU**
- The COP timer can make the MCU to have in energy saving state called sleep-mode by turning on and off the MCU.
- The ideal power saving mode as shown in below figure (right) shows the clear discrete mode with extremely lower of power consumption under the **power saving mode**. The UWLD with sleep-mode by the COP timer may have the continuous power consumption.
- The dual MCU system can be considered to achieve the **higher efficient power saving mode**.

*UWLD with sleep mode by the COP timer*

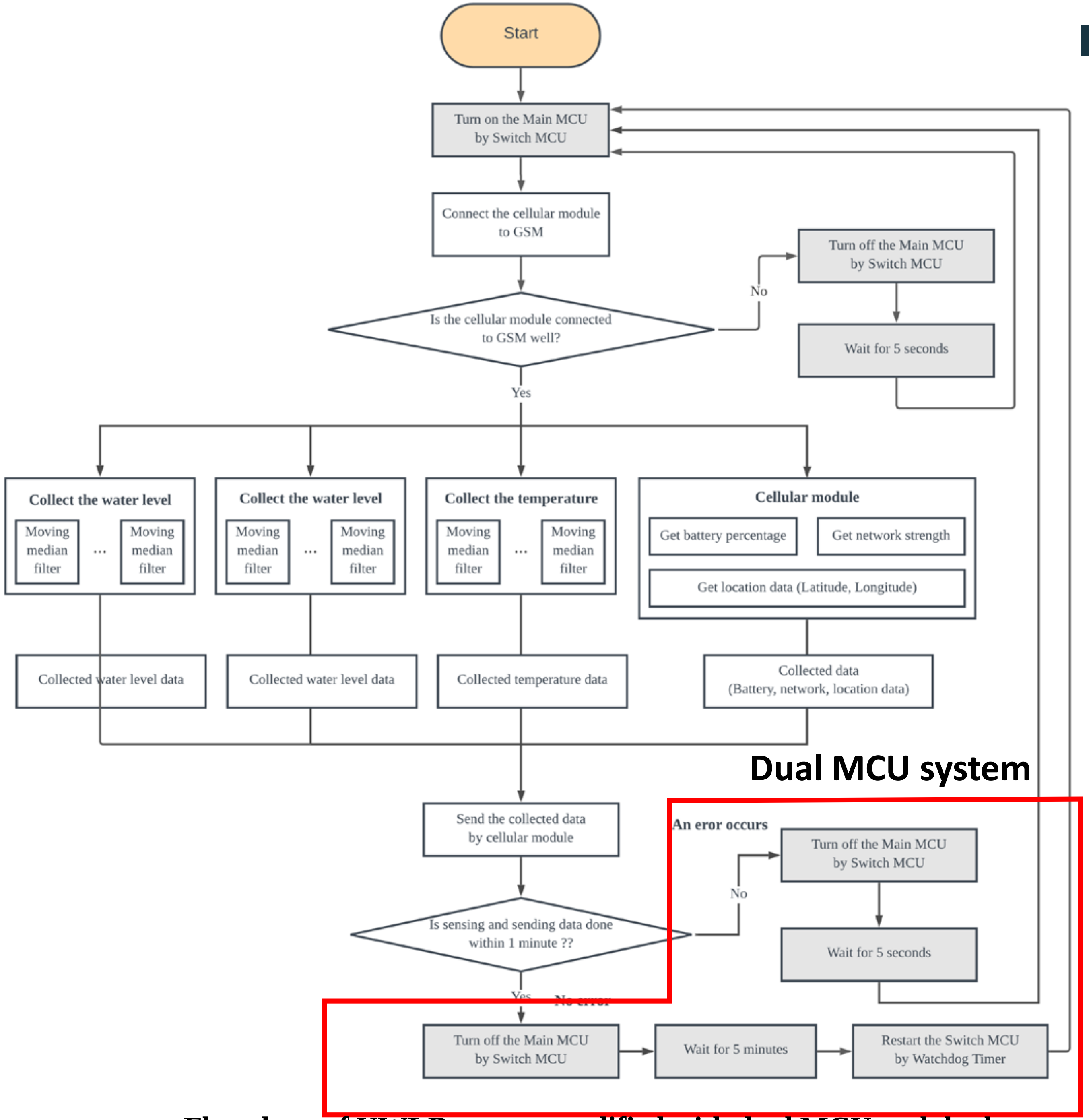



*Ideal power saving mode*




*System representation of proposed UWLD system with dual MCU*

- **Dual MCU** improves this inefficiency of the sleep mode by operating the additional low-powered MCU and solid-state **relay** (SSR), which has lesser power consumption.
- The original MCU will be called as **main MCU for** performing the **main task (e.g., collecting and sending data)**
- The added MCU will be called as **switch MCU** for **turning on and off the main MCU**




**Flowchart of UWLD system modified with dual MCU and dual target**

- If data processes on the main MCU are incomplete within 1-minute, it means the error occurs during the cycle. So the main MCU should be turned off immediately and re-process data collection and transmission again without interval time.
- If the data transmission by the Main MCU is finished in 1-minute, Main MCU is turned off by Switch MCU for 5 minutes (data collection interval).
- The Main MCU is turned on after 5 minutes of power saving mode by Switch MCU

# 3. Result

# Results: UWLD unit installation

- UWLD units have been installed near The University of Texas at Arlington (UTA), and they operate from end of February to end of August of 2020 for about six months.
- Two units were installed at two nodes, which does not hinder the public, and we did a regular check-up for unit condition (e.g., battery status and sensor orientation).
- From the 6-month period, data set were collected on the website and were periodically monitored until August 24th.


**Node 1**

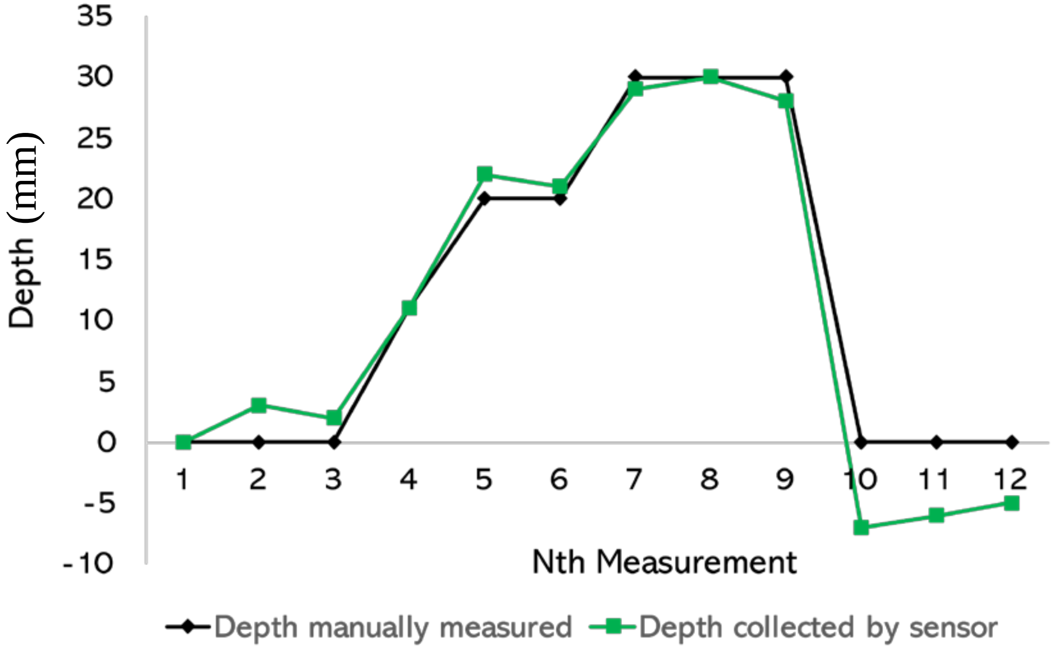
**Node 2**

**Installed and modules and locations (node 1 and node 2)**

# Results: Calibration on pavement

- The verified ultrasonic sensor distance data to check the accuracy

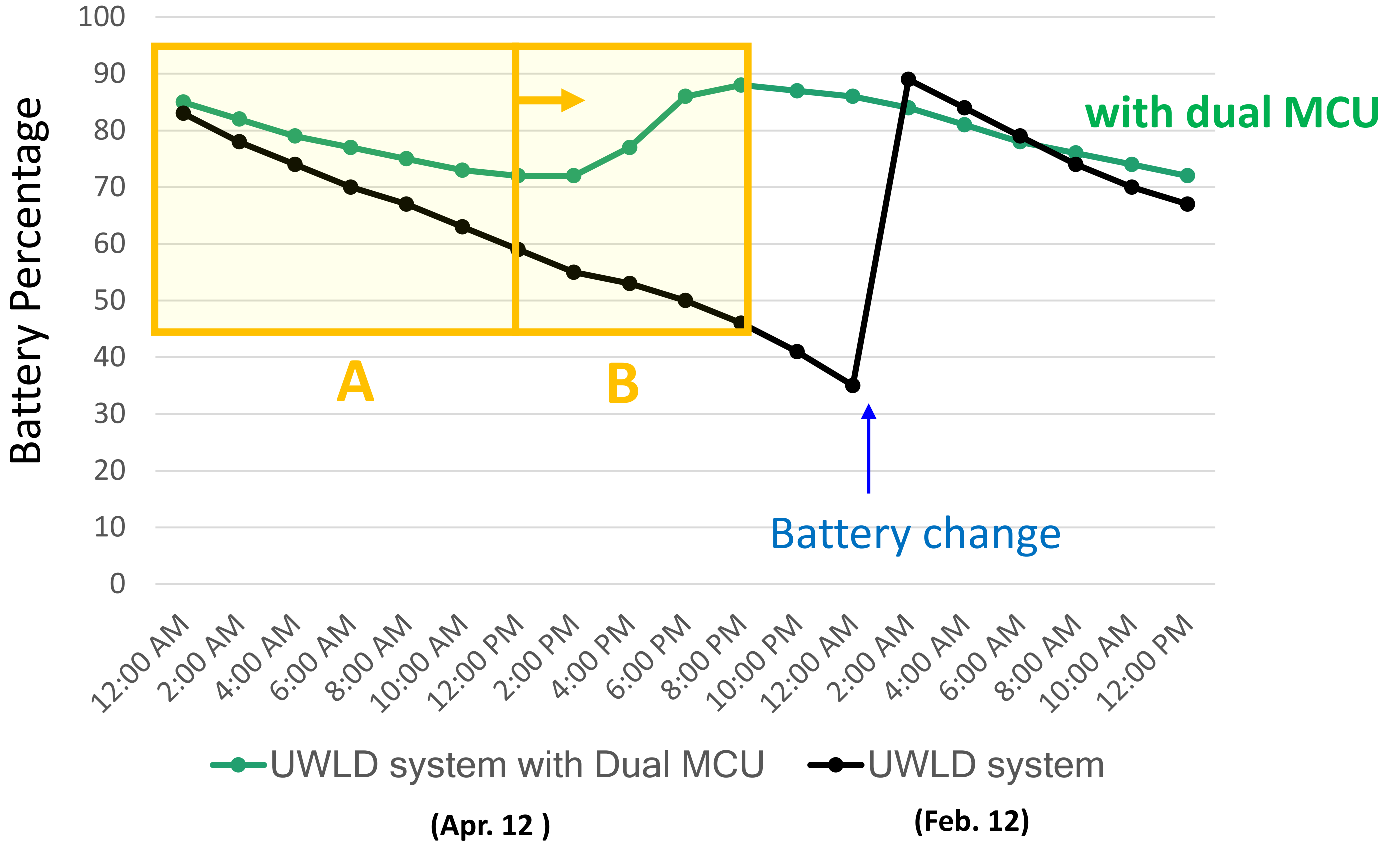
Ultrasonic sensor calibration test




Results by manually measured distance and ultrasonic sensor distance

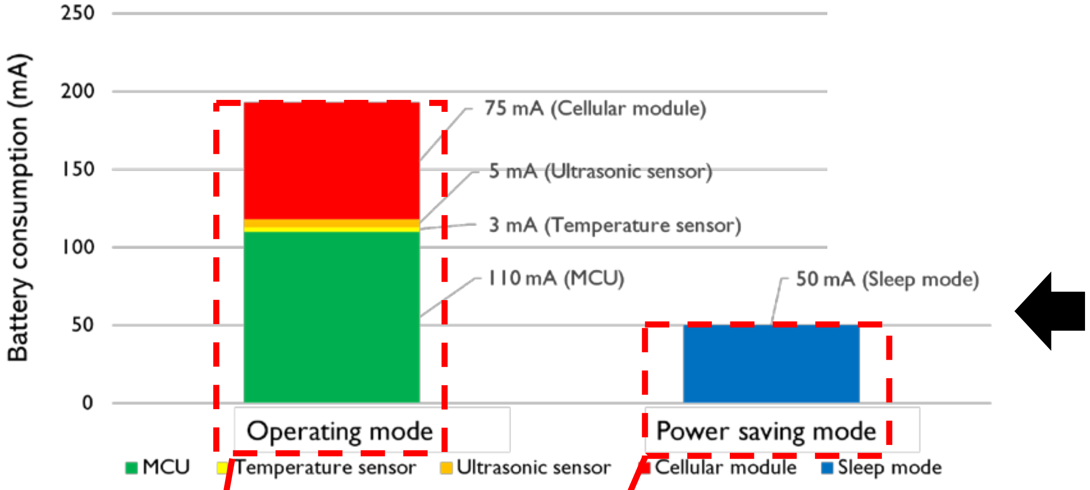
# Results: Energy efficiency

- There is a battery sustainability issue in the UWLD system.
- The comparison battery health curves are shown in below 36 hours monitoring data figure.
- A section presents higher energy efficiency at the UWLD system with dual MCU.
- B section shows how energy-saving <u>design affect power consumption.</u>



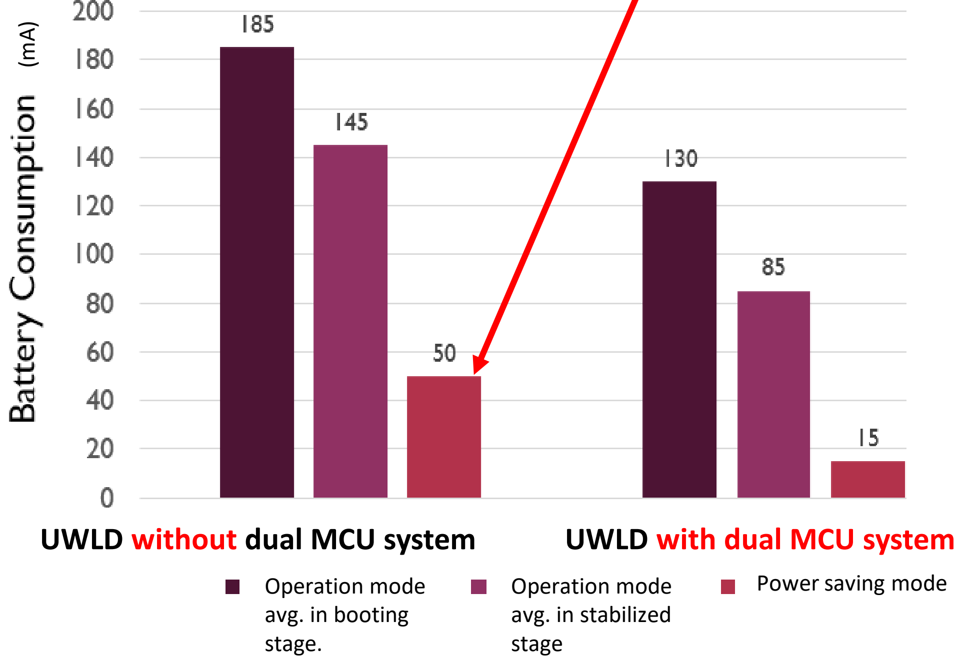

*36 hours battery percentage record comparison*

- Without dual MCU the battery consumption by each components is shown in below




**Battery consumption by each module**

**Without dual MCU**




***Battery consumption comparison***

- With **dual MCU system**, the power consumptions are decreased in both operating mod and power saving mode:

❖Operating mode (185mA → 130mA): **30 %** ↓

❖Power saving mode (50 mA → 15mA): **70 %** ↓

# Results: Relation UWLD system and NOAA

- NOAA, National Oceanic and Atmospheric Administration, provides water level of Lake Arlington, which is about 5 miles distance from the UWLD units installed near UTA.

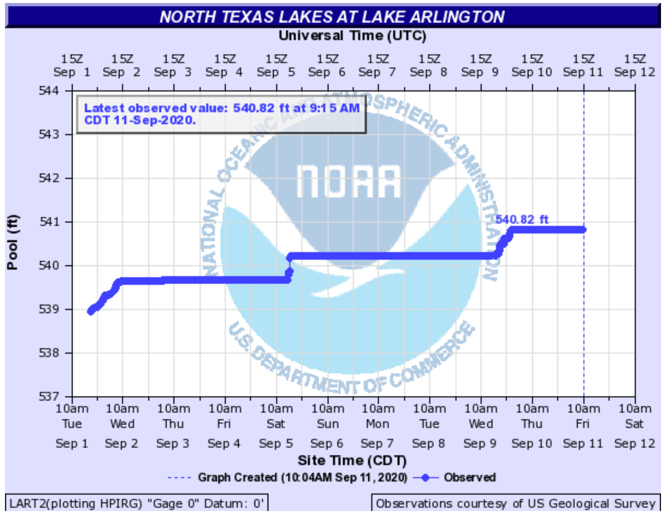
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| NESDIS ID | 171503B4 | NWS Location ID | LART2 | Owner | USGS01 | | |
| Location | LAKE ARLINGTON NEAR ARLINGTON 10W | | | | | | |
| Latitude | N 32°42'58" | Longitude | W 97°11'32" | HSA | FWD | State | TX |
| Channel | 70 | Transmission Interval (min) | 60 | Next Transmit GMT | 16:21:00 | Initial Transmit Time (HH:MM:SS) | 00:21:00 |

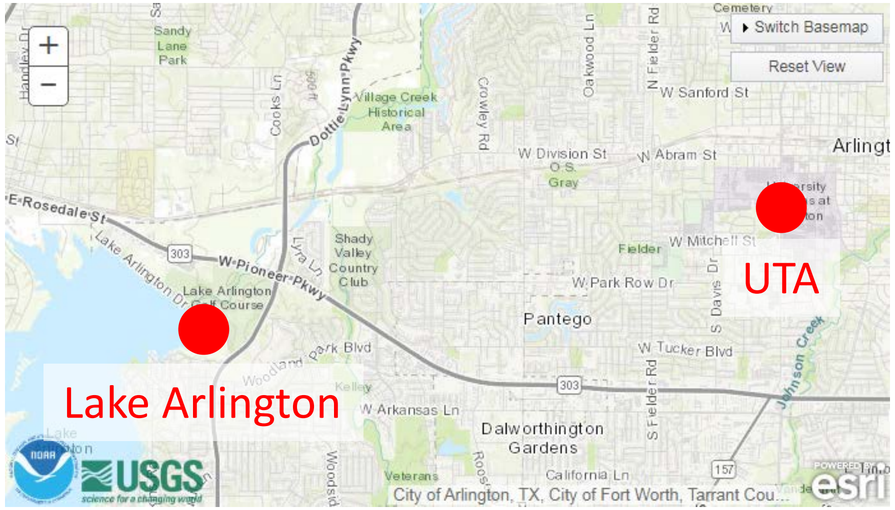
AHPS Point - *Experimental link function. The link may be dead or non-functional.*

Decode Information

| NWSLI | Data Interval(min) Self-time | Data Interval(min) Random | SHEF Code | Time Offset (min) | Coefficient Self-time | Coefficient Random | Constant | Base Elevation (ft) | Gage Correction |
|---|---|---|---|---|---|---|---|---|---|
| LART2 | 15 | | HPIRG | 6 | 0.01 | | 0 | 500 | 0 |
| LART2 | 15 | | PCIRG | 6 | 0.01 | | 0 | 0 | 0 |

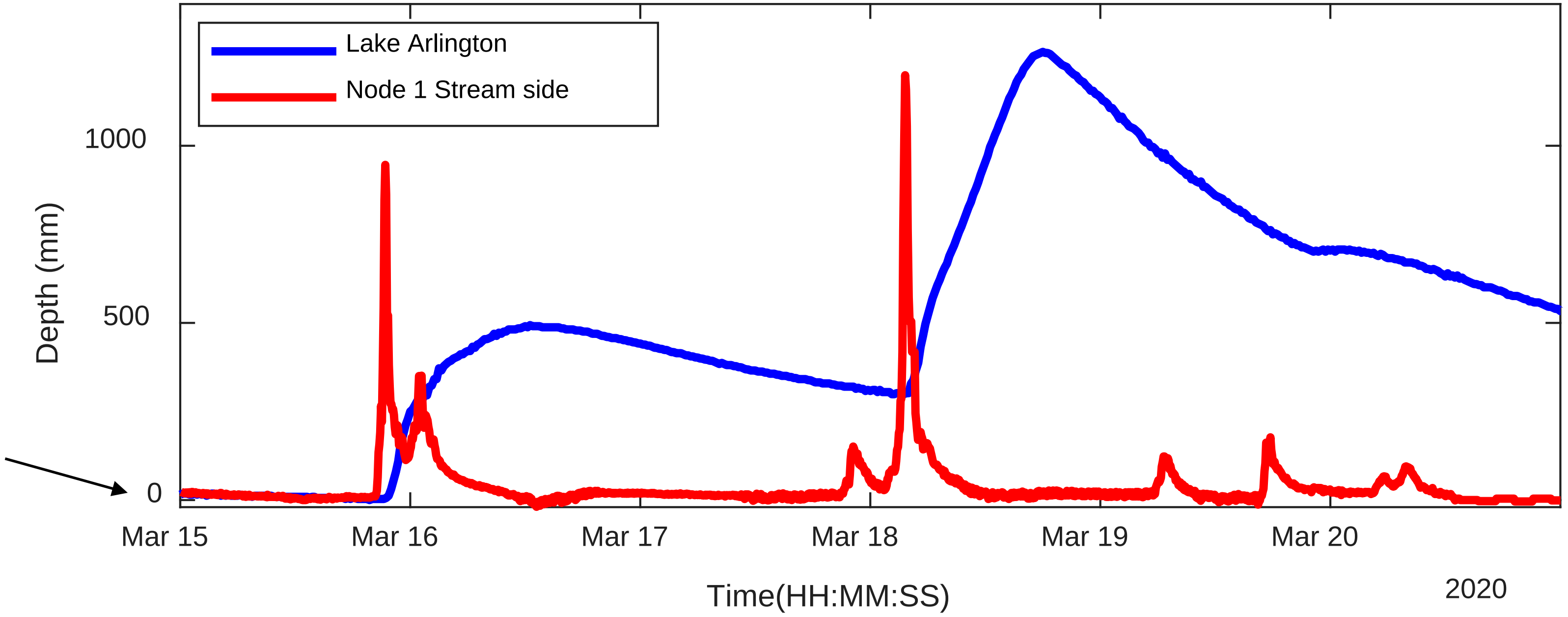
**Location and decode information of Lake Arlington water level detection**




**Example graph from NOAA**

- Below figure shows the water level comparison data from for 6 days monitoring results by UWLD system near the campus and Lake Arlington.
- During this period, 8 times water level peaks are monitored in UWLD stream side. But, at the lake only 2 peaks are captured due to its insensitivity by heavy rainfall.
- The figure shows the lake water level increases happened later than stream water level increases, and it implies the large-scale water body area is not much helpful to monitoring the flash flooding.



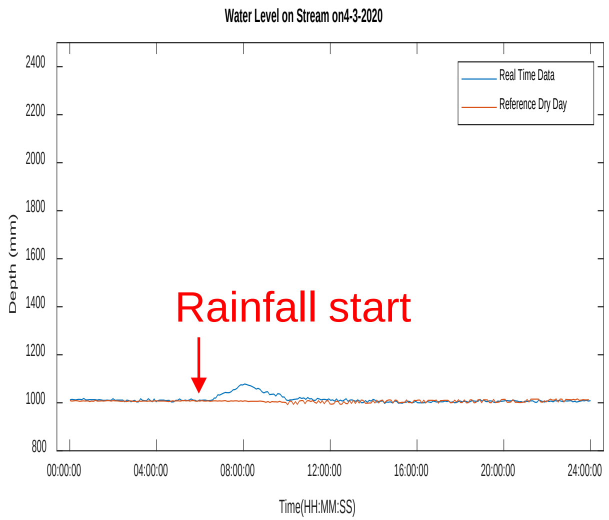

**Shift to 0** for the Lake Arlington water level

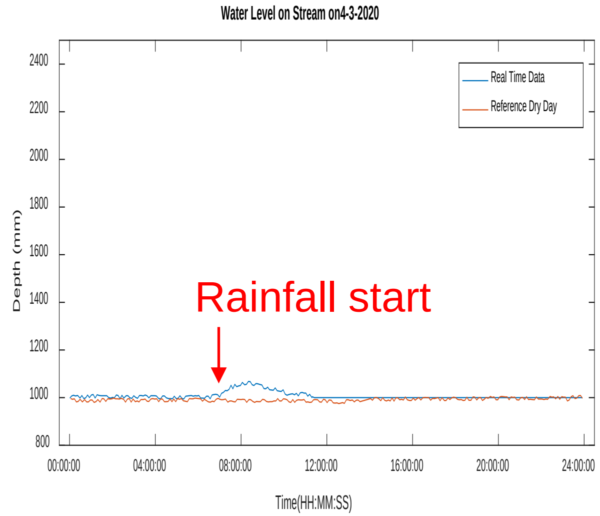
Node 1 stream side **0 water level** means UWLD system is detecting the **bottom of the stream (no water).**

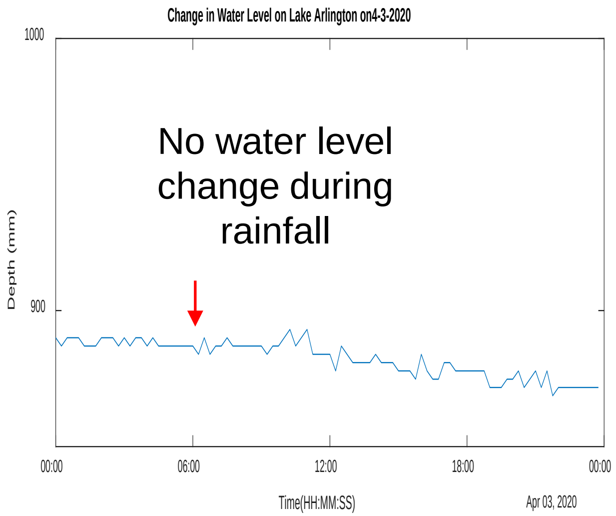
***Water level monitoring from Node 1 stream side and Lake Arlington for 6 days (Mar. 15 - 21)***

## UWLD at Node 1 | UWLD at Node 2 | Arlington Lake

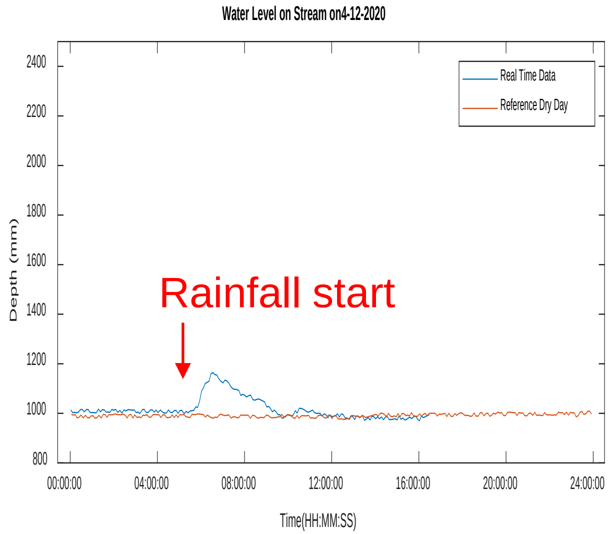
4/3/2020

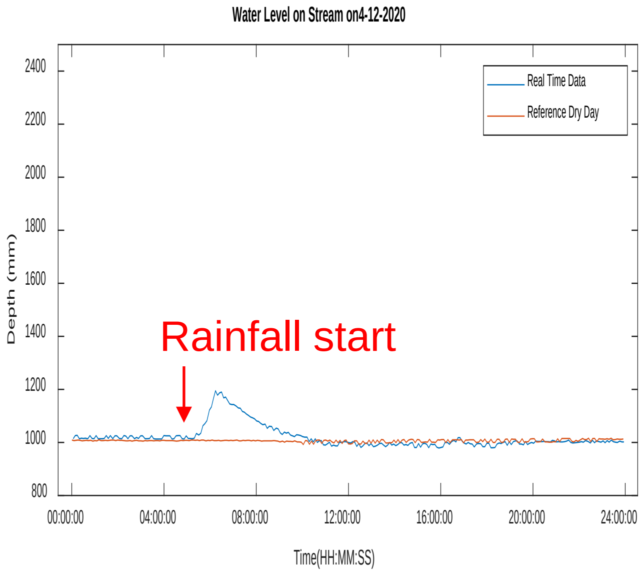


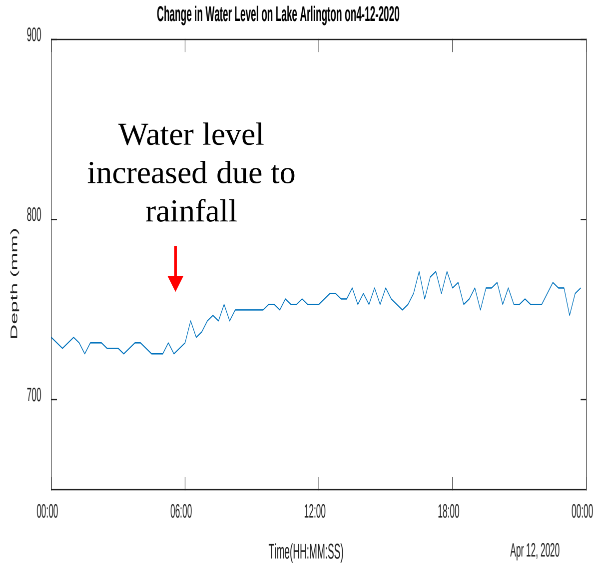




4/12/2020



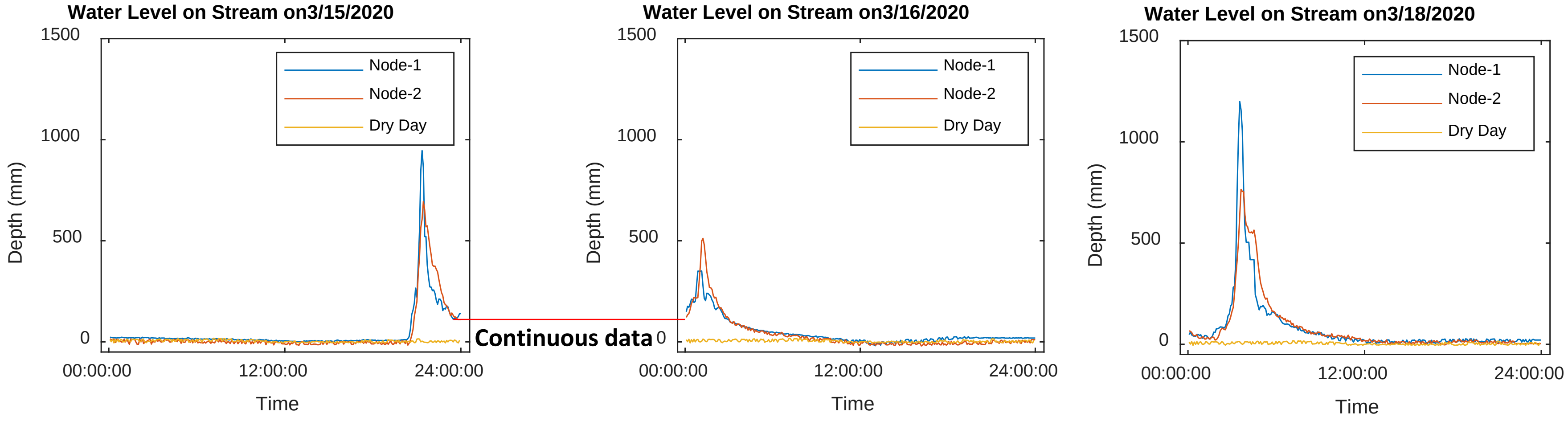




**Water level monitoring from Node 1 stream side and Lake Arlington for 6 days (Mar. 15 - 21)**

# Results: Relation Node 1 and 2 of UWLD system

- We installed UWLD units under the similar condition of stream as Node 1 and Node. All stream data show the similar water level change.
- Correlation analysis for the data from two nodes presents how reliable water level change is monitored to identify the tendency of rainfalls.
- The correlation coefficient are calculated based on 10 rainy days data.




*Correlation coefficients between Node 1 and 2 in the rainfall dates* *Average: 0.932*

| 3/14 | 3/15 | 3/16 | 3/18 | 3/20 | 3/21 | 4/3 | 4/12 | 5/25 | 6/21 |
|---|---|---|---|---|---|---|---|---|---|
| 0.9257 | 0.9270 | 0.9391 | 0.9047 | 0.9325 | 0.9617 | 0.8930 | 0.9481 | 0.9501 | 0.9367 |

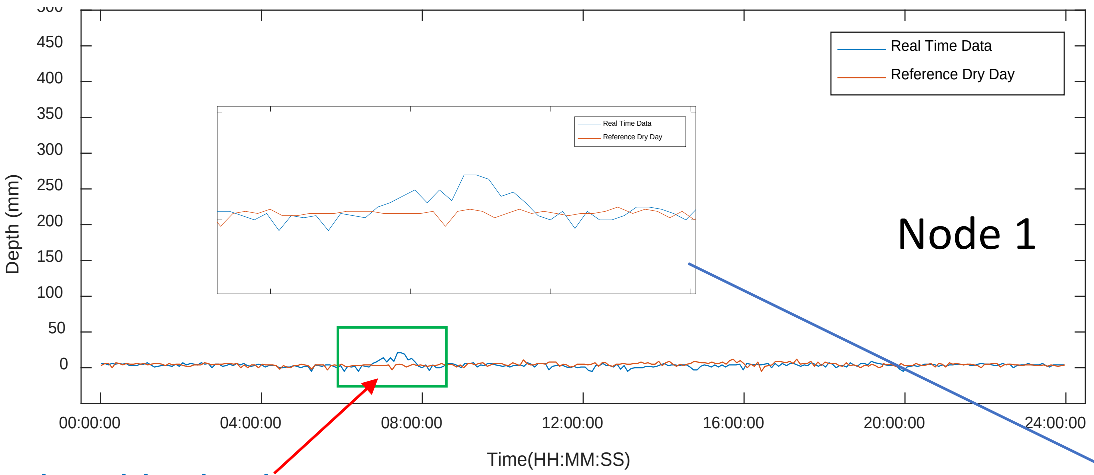
Pearson's correlation coefficient ($r$)

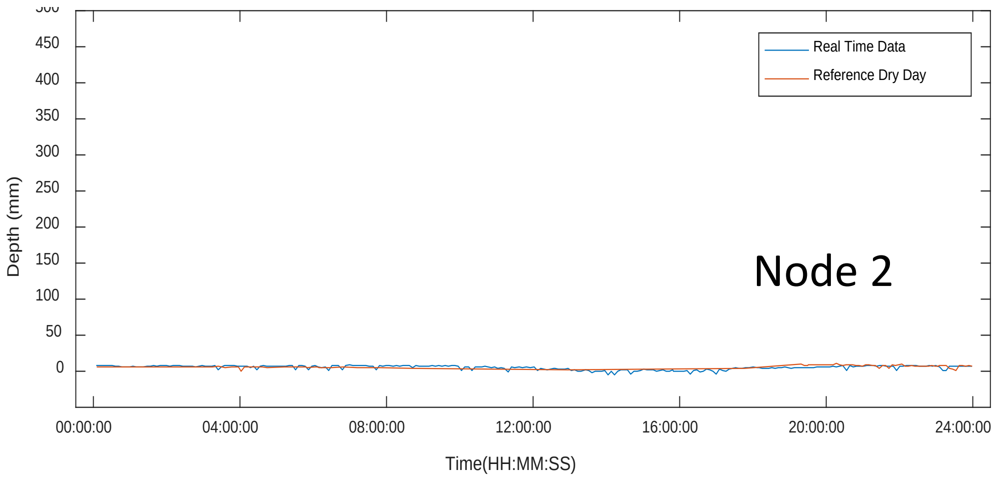
$$r = \frac{\sum_{i=1}^{n}(X_i)-\mu_X(Y_i-\mu_Y)}{\sqrt{\sum_{i=1}^{n}(X_i-\mu_X)^2\sum_{i=1}^{n}(Y_i-\mu_Y)^2}}$$

- The correlation analysis indicate the measured distance data from two UWLD units shows strong correlation, and it implies the relatively closer locations than the rainy area show the similar tendency of rainfall.

# Results: Relation of pavement and stream side water level

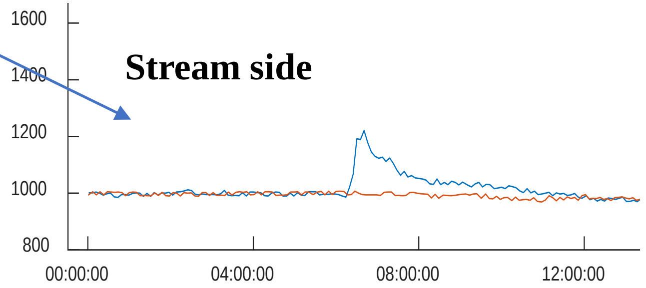
- On periodic monitoring, we found that the pavement side of the bridges has an extremely small change of water level due to the good drainage system of the bridge.
- But on a certain case, we found that the water level rise on the sidewalk of Node 1 due to the rainfall, which may be due to stagnation of water or any other obstacle in the pavement side.
- Whereas at Node 2 on the same day, we found the same level of water level rise in the streamside but a good drain of water at the sidewalk.




Water level by bad drainage

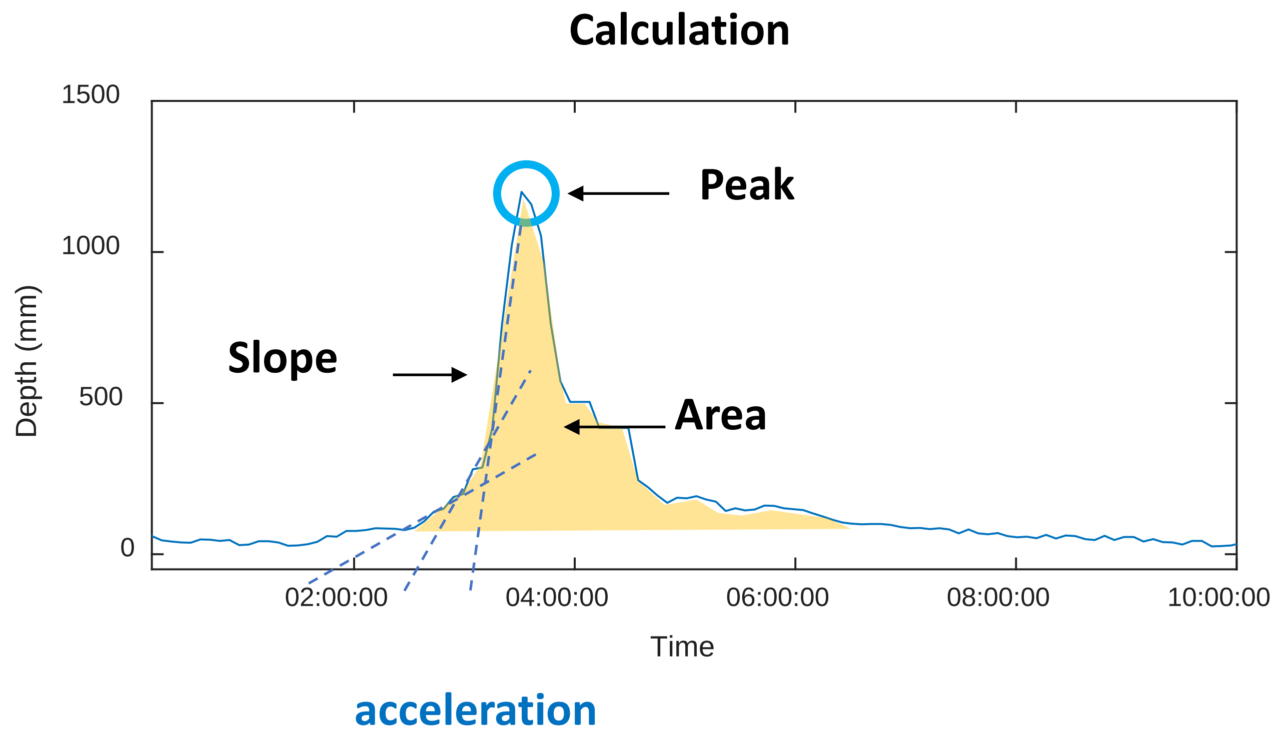
**Pavement side water level change on Jul. 6**

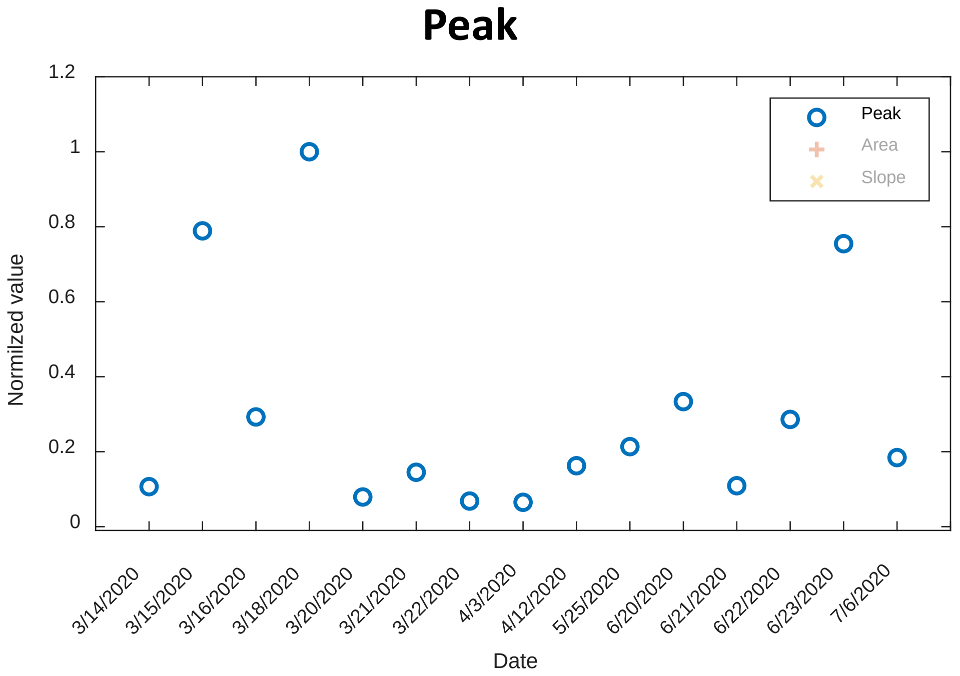



- Although, we could detect one case the pavement side water level change in the monitoring period, it is significant for the urban inundation when the location continuously exposes the bad drainage condition.

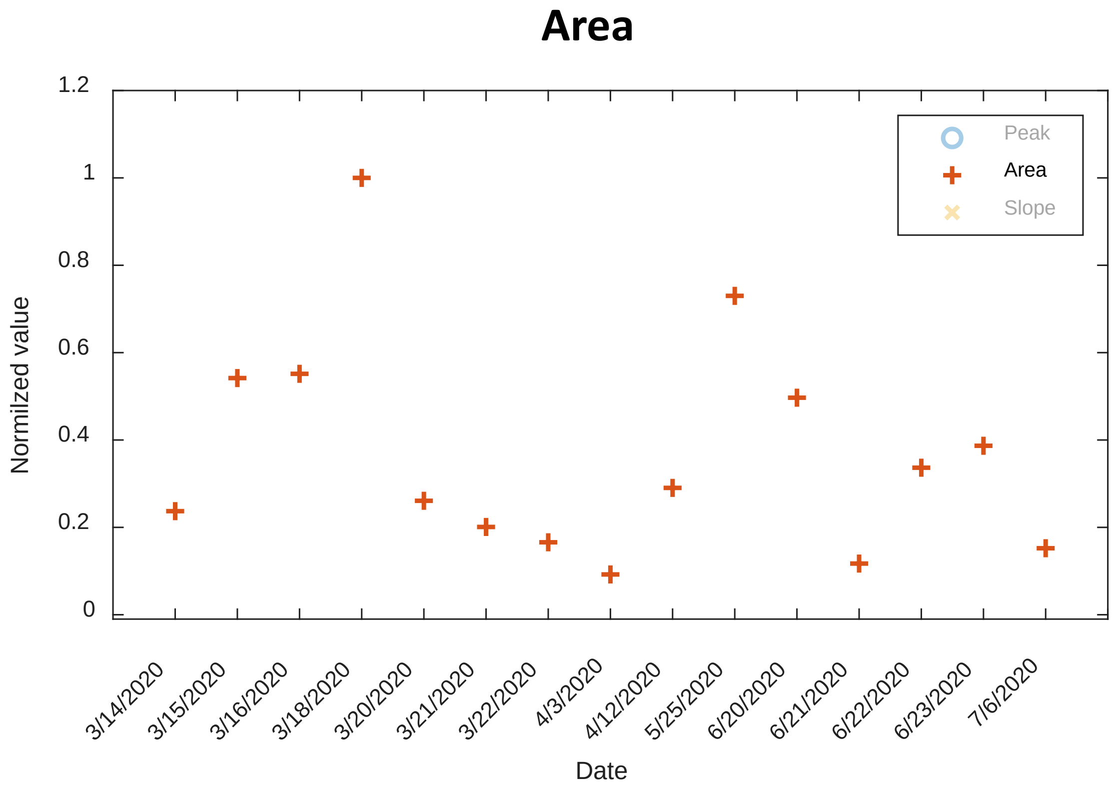
# Results: Water level monitoring result

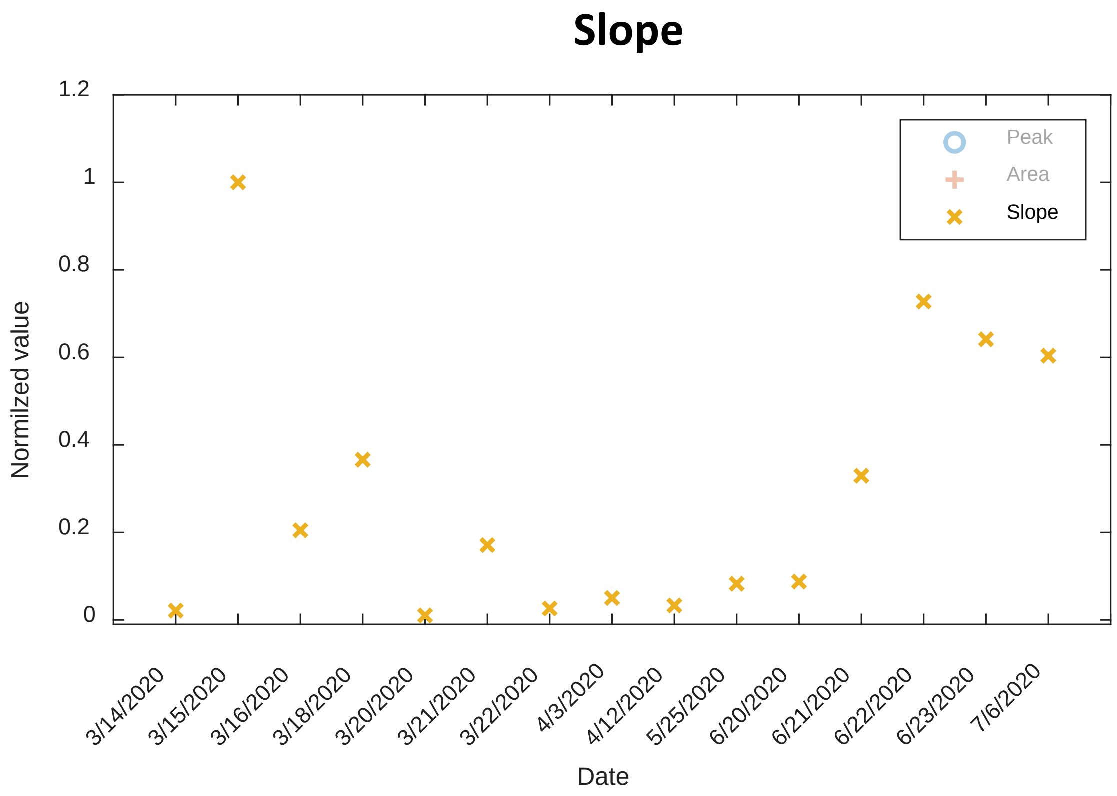
- We analysis the UWLD monitoring data in three different indicator: peak and area of the rainfall curve and slope of water level increasing point and peak point.
- The quantified values are calculated as shown in below figure (left)
- Peak point can indicate the amount of rainfall under the same drainage system (below right figure).



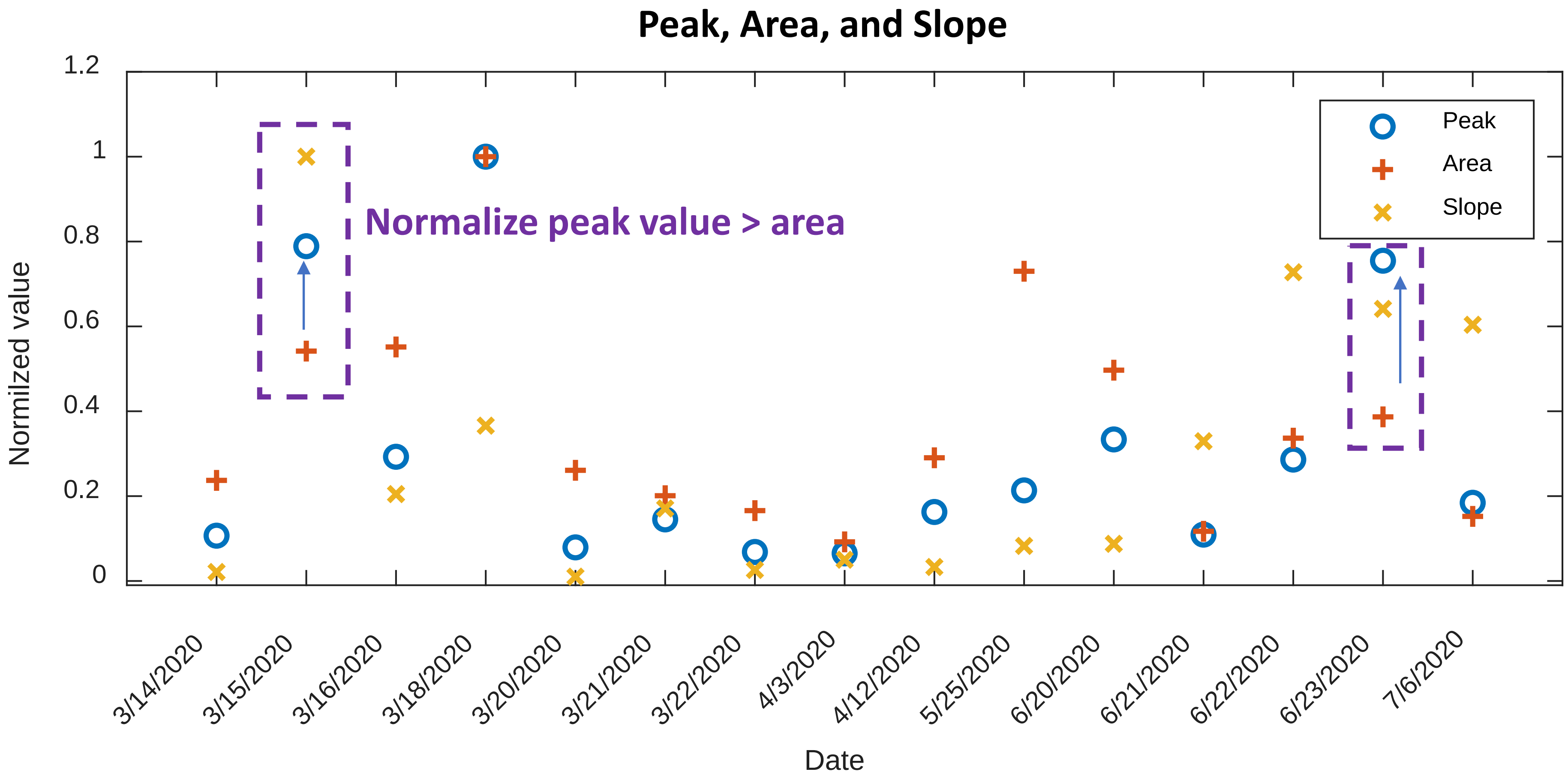



- Area of the monitored water level curve also can indicate the amount of rainfall under the same drainage system.
- The slope of the initial raising region can show how precipitous increase of the rainfall.



- Comparison the quantified peak, area, and slope values can describe the tendency of the rainfall.
- Case of high peak value and low area indicates the rainfall is heavy rain (high change of flash flood).
- Case of lower slope and lower peak indicates the moderate rainfall.



# Conclusion

The real-time water level monitoring was conducted with the measured water level data by the developed UWLD system and real-time monitoring system through AWS. The dual MCU system was considered to build the efficient power supply and consumption, and dual targets of the water level detection are considered to study the relationship between the water level change by the targets in different amount and duration of rainfall.

- The UWLD system was developed to measure the water level and transfer the data to the AWS server; the obtained water level is calibrated with the ultrasound wave velocity change by the temperature. In addition, the accuracy of the distance measurement was verified with manually measured distance.

- From the UWLD system, a total of 15 rainfall events with water level changes were detected for six month monitoring period (March 1st to August 24th, 2020).

- As the streamside water level increases from our UWLD system, the lake water level data did change or increased later. It implies that the water level change at a local small creek or stream represents a more sensitive flood level indication than at the large water bodies (e.g., lake or sea level). Thus, it is significant to consider the intensity of the rainfall from the streamside as well

# Conclusion

- The water level change on the pavement side is not always detected as streamside water level change due to the good drainage system. Among 30 cases of the monitoring water level on the pavement side, only 3 cases (March 16th, 18th, and July 6th) presents the pavement side water level changes during the rainfall at the Node 1 location. The pavement side water level changes may present more significant flash flood risk and affect infrastructure conditions (e.g., the drainage system) then the direct rainfall intensity from stream water level, especially close to the area of UWLD station.

- The water level monitoring of dual targets, pavement side, and streamside, can give more reliable and sensitive information to perceive and forecast the urban flash flooding.

- The battery power efficiency was improved for the stable operation of the UWLD system deploying the dual MCU unit, which is composed of the additional MCU (switch MCU) and SSR for controlling the main MCU. The dual MCU system reduced the power consumption of the averaged current consumption, 30 % reduction in operating mode, and 70% reduction in power saving mode. It is significant for the power saving during solar power charging, which is affected by the external environment (e.g., rainfall and cloudy day)

# Thank you and Q&A

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